AN ABSTRACT OF THE THESIS OF

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Title: Comparison of Relationship between Accelerometer Outputs and Energy Expenditures in People with and without Down syndrome during Walking Activity

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In recent years, there has been an increased interest in accurately measuring physical activity levels with accelerometers. Two distinct approaches have been used to estimate physical activity levels with accelerometers are vertical axis activity counts and vector magnitude (VM). Although previous studies evaluated these two distinct approaches for individuals without disabilities, employing VM may have a greater advantages for people with Down syndrome (DS) because of their unique movement pattern of increase movements along the mediolateral axis during walking. The purpose of this study was to identify which approaches, to physical activity monitoring, can better predict physical activity levels for people with and without DS while walking. A total of 37 participants completed the testing protocol, 18 participants with DS (age 19 – 64 years; 32.56 $\pm$ 14.16) and 19 participants without DS (nDS; age 19 – 64 years; 31.61 $\pm$ 12.90). All participants took part in one session of data collection involving walking at different speeds. Participants wore a GT3X+ triaxial accelerometer on their right hips to measure

activity counts, a Oxycon Mobile System on the front of their body to measure energy expenditure, and a heart rate monitor to measure approximate relative intensity during testing protocols. All participants were asked to walk at three different speeds for six minutes at each speed of self-selected speed, slow speed (2 mph), and fast speed (4 mph) in a figure “8” shape with a five minute break between each trial. During the slow and fast speed trials, a trained pacer along with a calibrated wheel and speedometer walked in front of all participants to ensure maintenance of speed. The results showed the correlation between energy expenditure and accelerometer outputs, both vertical axis activity counts and VM for individuals without DS are 0.75 at a group levels using linear mixed effect models. And the correlation coefficient between energy expenditure and vertical axis activity counts and VM for people with DS are 0.53 and 0.64, respectively. There werer no significant difference between the correlations for the without DS group and a correlation approaching significance for the DS grou when comparing the correlation with energy expenditure between vertical axis activity counts and VM. Significant differences were found between groups when comparing correlation coefficients with energy expenditure and vertical axis activity counts using z – test ($z = 1.99$, p-value = 0.046). No significant difference was found between groups when comparing correlation coefficient between energy expenditure and VM ($z = 1.06$, p-value = 0.29). For people without DS, this study supported that using either approach yielded similar results. This result was surprising given the unique characteristics of people with DS. Additional studies are needed to continue to determine the accuracy of

the accelerometer in measuring physical activity levels for people with DS accounting for their unique characteristic.

Comparison of Relationship between Accelerometer Outputs and Energy Expenditures in People with and without Down syndrome during Walking Activity

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Ch. 1 Introduction

Past research has consistently demonstrated the importance of regular physical activity engagement (Bartlo & Klein, 2011; Janssen & LeBlanc, 2010; Johnson, 2009; Warburton, Nicol, & Bredin, 2006). According to the *2008 Physical Activity Guidelines*, it is currently recommended that adults should engage in a minimum 150 minutes of moderate to vigorous physical activity each week. Physical activity levels can serve as an indicator for health status; therefore there has been an increased interest in accurately measuring physical activity levels of individuals recently (Haskell, Blair, & Hill, 2009). A wide variety of methods and approaches have been implemented in measuring physical activity levels. In addition to the traditional questionnaire-based methods, objective methods, (e.g. accelerometey base motion senors) have become popular in assessing physical activity levels (Rowlands, 2007).

A host of previous studies used accelerometers to examine physical activity levels among people, both with and without disabilities (Dixon-Ibarra, Lee, & Dugala, 2013; Izquierdo-Gomez et al., 2014; Taylor & Yun, 2006; Temple, Anderson, & Walkley, 2000; Troiano et al., 2008). Specifically, accelerometers measured the displacement of acceleration during movements (Chen & Bassett, 2005). These recorded basic units of accelerometer measuring physical activity are called activity counts, which may be collected along the three movement axes, vertical, anteroposierior, and mediolateral axis (Chen & Bassett, 2005). While these accelerometer outputs are unitless, they are

proportional to energy used during movements (Melanson & Freedson, 1996). For example, higher activity counts indicated higher energy expenditure during movements (Melanson & Freedson, 1996). This is useful in measuring physical activity levels, as it can be used to indicate categorical physical activity (e.g., sedentary, light, moderate & vigorous).

The currently popular triaxial accelerometer measures activity counts for the three specific axes, vertical, anteroposterior, and mediolateral axis (Chen & Bassett, 2005). Vertical axis activity counts are based solely on the movements along the vertical axis. Movements data regarding movements along the anteroposterior axis are recoded only along the anteroposterior axis. And mediolateral axis activity counts are recorded based on the movements along the mediolateral axis. Activity counts recorded for each axis are movements along that specific axis and only estimate energy expenditure along their respective axis (Mathie, Celler, Lovell, & Coster, 2004). One way to combine these three axes is using vector magnitude (VM). VM is an accelerometer output that considers activity counts from the three movement axes using the equation of $\sqrt{x^2 + y^2 + z^2}$ or the Eucldean norm (Bouten, Westerterp, Verduin, & Janssen, 1994). This equation summarizes the activity counts from all movements axes and estimating energy expenditure based on movements along all axes.

Accelerometers have been deemed reliable in measuring physical activity levels and estimating energy expenditure (Kelly et al., 2013) but they utilize a threshold or cut point to categorize physical activity intensity. To interprete accelerometer outputs in regards to physical activity levels, cut points are used (Chen & Bassett, 2005). It is

important to note that cut points are typically developed using accelerometer outputs and/or activity counts. Currently, the two distinct types of accelerometer outputs being used to develop cut points are using activity counts from vertical axis only and VM. Past studies had used both approaches of cut points to measure physical activity levels (Mota et al., 2007; Romanzini, Petroski, & Reichert, 2012).

Using accelerometers to measure physical activity levels of individuals with Down syndrome (DS) has been completed in many studies (Jeong, 2012; Nordstrøm, Hansen, Paus, & Kolset, 2013; Phillips & Holland, 2011). A recent study showed that individuals with DS have lower physical activity levels, when measured with accelerometry, when compared to their peers without disabilities and similar ages (Phillips & Holland, 2011). However, there are mixed results from studies comparing individuals with and without intellectual disability regarding physical activity levels (Temple, Frey, & Stanish, 2006). A systematic review investigating the physical activity levels of people with intellectual disabilities suggested less time spent engaging in physical activity when compared to their counterparts might be an assumption (Stanish, Temple, & Frey, 2006). By way of illustration, one study showed that when comparing the physical activity levels between children with DS and their similar-aged siblings in the same environment using biaxial accelerometers, both groups had similar activity levels (Whitt-Glover, O'Neill, & Stettler, 2006a). These contradicting results may be due to the accuracy of accelerometer output approaches in measuring physical activity levels using accelerometer.

The unique movement characteristics of individuals with DS present significant challenges for using the uniaxial accelerometer to measure physical activity levels. Smith, Stergiou, and Ulrich, (2011) reported that individuals with DS displayed a different gait pattern than individuals without disabilities; this includes an increased movement along the mediolateral axis during gait cycle (Agiovlasitis, McCubbin, Yun, Mpitsos, & Pavol, 2009; Kubo & Ulrich, 2006). Thus, using the vertical axis activity counts based cut point to categorize physical activity levels of individuals with DS might be inadequate because this measurement might neglect the increased movement along the mediolateral axis during walking activities of individuals with DS. The VM approach could capture the increased mediolateral movements of individuals with DS. Sirard and Pate (2001) suggested that the frequent used uniaxial approach may be limited in its ability to detect the variability of movements. Therefore, there is a need to validate the different approaches in estimating physical activity levels of unique movement patterns, specifically in populations where known differences in movement exit like those of individuals with DS (Bjornson, 2005).

The purpose of this study was to examine the accuracy of accelerometer outputs among individuals with and without DS in predicting energy expenditure.The relationship between accelerometer outputs and energy expenditure needs to be examined for a better understanding of which approach, the uniaxial approach of vertical axis activity counts or triaxial approach of VM from accelerometer outputs, can better predict physical activity levels for individuals with and without DS. The following specific aim and hypothesis were tested.

The *Aim* of the study was to identify which accelerometer output (vertical axis activity counts and accelerometer output of VM) would have a better correlation with energy expenditure among individuals with and without DS during walking activity.

Working Hypothesis 1: There are correlational differences with energy expenditure between the vertical activity counts and VM among individuals with DS.

Working Hypothesis 2: There are correlational differences with energy expenditure between individuals with and without DS in vertical axis activity counts.

Working Hypothesis 3: There are correlation differences with energy expenditure between individuals with and without DS in VM.

Assumptions

The follow assumptions were made in this study.

- The walking speed of 2 mph and 4 mph represented light and moderate physical activity levels, respectively, for all individuals (Ainsworth et al., 2011).
- A 5 minute break between each walking trials is a sufficient duration for metabolic rate return to resting levels.

Delimitations

The following delimitations were made in this study.

- All participants were adults recruited from the Pacific Northwest region of the USA.
- The order of walking trials was the same for all participants, from self-selected speed, slow speed, and fast speed.

Operational Definitions

Physical Activity: Any bodily movements resulting in energy expenditure.

Accelerometer: Physical activity tracking devices using acceleration.

Activity Counts: Accelerometer outputs that are unitless but proportional to energy expenditure.

Vertical Axis Activity Counts: Accelerometer outputs based on the vertical axis.

Vector Magnitude: Summary of activity counts from all three-movement axis of vertical, anterioposterior, and mediolateral axis.

Chapter.2 Literature Review

The purpose of this literature review is to provide the readers with background information on Down syndrome (DS), the usage and basic understanding of accelerometer outputs and cut points in measuring physical activity levels, and methods in comparing correlation coefficients with overlapping variables. Despite the availability of triaxial accelerometer based motion sensors, majority of physical activity assessment literature often utilizes uniaxial measurement to assess physical activity (Butte, Ekelund, & Westerterp, 2012). This literature review will present multiple studies in which examining the accuracy of triaxial and uniaxial approaches in measuring physical activity levels among individuals with and without disabilities, as well as describe the rationale for this study. For organizational purposes, this literature review is presented in the following order: Down syndrome, physical activity levels of individuals with DS, gait patterns of individuals with DS, motion sensors, accelerometer outputs, cut points and thresholds, comparison of uniaxial and triaxial approaches, accelerometers and individuals with DS, and examining the association between overlapping correlation.

Down syndrome

Down syndrome (DS) is a genetic disorder caused by the presence of an extra chromosome(s) and leads to developmental delays and intellectual disability (Evans-Martin, 2009). The incidence of DS ranges from 1 in 600 to 1 in 1,000 live births (Evans-Martin, 2009). Common physical characteristics of DS include low muscle tone, poor reflexes, joint laxity, short status, and flatter back of the head (Block, 1991). Facial features of individuals with DS include a flat face, small nose with a flat nasal bridge,

small oral cavity, small palpebral fissures, Brushfield spots (small white spots on the iris), and epicanthal folds (Cunningham, 2010; Evans-Martin, 2009). Due to their short status, individuals with DS also have shorter fingers where the fifth finger may curve inward along with a larger gap between the first two toes of the feet (Evans-Martin, 2009).

Individuals with DS have a decline in intelligence as they age (Evans-Martin, 2009). It is found that their IQ test scores do not match their physical age, where they had a lower mental age compare to their physical age (Cunningham, 2010). The lower IQ scores can be explained by the disproportionately smaller brains of individuals with DS as compared to individuals without DS (Evans-Martin, 2009). Their smaller brain sizes may affect the overall cognitive functions of the individuals with DS (Evans-Martin, 2009).

Types of Down syndrome

There are different types of DS, due to variation in the cause, but they all result in the same characteristics and physical features with different levels of severity (Block, 1991; Cunningham, 2010). Trisomy 21 represents about 90 to 95 percent of all DS cases, thus the most common type of DS (Selikowitz, 2008). Trisomy 21 occurs when an individual possesses an extra copy of chromosome 21 (Evans-Martin, 2009), which results in a total of 47 chromosomes instead of the 46 in individuals without DS (Evans-Martin, 2009; Margulies, 2007). Translocation, another type of DS occurs when either a part or all of chromosome 21 is transferred to chromosome 14 (Evans-Martin, 2009). The last type of DS is mosaicism, the least common type of DS, which can occur in two ways: 1) When the zygote starts with 47 chromosomes, and subsequently undergo a

second nondisjunction during mitotic cell divisions (Selikowitz, 2008), or 2) when a 46-chromosome zygote undergoes nondisjunction during mitotic cell division (Cunningham, 2010). Mosaicism results in some cells or tissues having trisomy 21 and others not (Evans-Martin, 2009). Mosaicism may only affect a portion of the cells of tissues or all the cells of tissues. Therefore, on average, mosaicism may result in fewer characteristics of DS on average (Evans-Martin, 2009).

Associated Challenges with Down syndrome

Many individuals with DS have significant health concerns. About 60 percent of newborns with DS are born with congenital heart defects, including those that affect either the valves or the walls between the chambers of the heart (Block, 1991). Other health concerns include gastrointestinal, respiratory, vision, hearing, skin problems, immunological problems, and hypothyroidism (Cunningham, 2010; Evans-Martin, 2009; Urbano, 2010). Hypothyroidism can affect brain function by causing ataxia, confusion, hallucinations, psychotic behaviors, and anxiety (Evans-Martin, 2009; Urbano, 2010). Joint laxity and hypotonia are the most common musculoskeletal problems among individuals with DS (Cunningham, 2010; Evans-Martin, 2009; Urbano, 2010). Due to joint laxity, individuals with DS may develop atlantoaxial instability (Evans-Martin, 2009; Urbano, 2010). Atlantoaxial instability refers to the instability of the first two vertebrae in the neck, which can cause damage to the spinal cord if the two vertebrae slip and result in atlantoaxial subluxation (Evans-Martin, 2009; Urbano, 2010).

The low muscle and joint laxity of Individuals with DS limit their ability to perform motor skill (Evans-Martin, 2009). They usually take longer to reach

developmental milestones, such as sitting up, crawling, and walking (Cunningham, 2010). In comparison to children without DS, children with DS stand on their feet by the age of two rather than at the age of one (Cunningham, 2010). Palisano and colleagues (2001) studied the motor function of 121 children with DS between the ages of one to six years and found that it took more time for them to master motor skills, movements, and other more complex skills. There are also signs of delays in grammar mastery and language development, as well as vocabulary skill deficits (Evans-Martin, 2009).

Physical Activity Levels of Individuals with DS

For adults living with intellectual disability in a community, including indivdiuals with DS, the most popular form of physical activity is walking (Draheim, Williams, & McCubbin, 2002). There is only a small number of adults with intellectual disability that engage in vigorous physical activity leisurely (Draheim et al., 2002). The second most popular physical activity for adults with intellectual disability is cycling (Draheim et al., 2002). Walking and cycling are likely the most popular forms of physical activity because both act as primary modes of transportation (Draheim et al., 2002; Stanish & Draheim, 2005). However, studies have shown that individuals with DS have a lower walking economy than their peers without DS due to an inefficient walking pattern which ultimately requires higher energy expenditure (Mendonca, Pereira, Morato, & Fernhall, 2010).

While individuals with DS participate in a wide variety of culturally relevant leisure activities, such as soccer, biking, running, and many more, a large proportion fail to meet the national recommendations for physical activity (Pitetti, Baynard, &

Agiovlasitis, 2013). Barriers to physical activity for individuals with DS include health concerns, such as heart conditions and hip problem, low physical fitness levels, low motor skills, negative public attitudes toward people with disabilities, lack of friends, transportation difficulties, and lack of accessible, inclusive, and properly designed programs (Pitetti et al., 2013).

Many adults with DS are more likely to fail to meet the physical activity recommendations of 150 minutes of moderate and vigorous physical activity (MVPA) per week when compare to their counterparts using acceleromters (Philips et al., 2011). Phillips and Holland (2011) investigated the physical activity levels of 79 individuals with DS using uniaxial acceleroemters and found that none of the participants met the physical activity guideline recommendations. They also found that individuals with intellectual disabilities spent less time engaging in physical activity and more time in sedentary activities as compared to those without DS (Phillips & Holland, 2011). In addition, Izquierdo-Gomez et al. (2014) found only 43% of adolescents with DS between the ages of 11 to 20 years, out of 100 adolescents with DS met the physical guidelines when using accelerometer as measurement tool. Similar results were found in a study by Shields, Dodd, and Abblitt (2009) about the physical activity levels of children with DS, where only 42.1% of children with DS with the mean age of 11.7 years were meeting the physical activity guidelines for children. A study by Whitt-Glover, O'Neill, and Stettler (2006) investigating the physical activity levels of children with DS and their similar aged siblings found children with DS spend less time in moderate and vigorous physical activity. Compared to other developmental disabilities (e.g. Williams syndrome

and Prader-Willi syndrome), people with DS are likely to spend more time in light physical activity but spend less time in MVPA (Nordstrøm et al., 2013). As individuals with DS increase in age, they tend to increase sedentary behaviors and decrease time spent in MVPA when measured with accelerometry (Esposito, MacDonald, Hornyak, & Ulrich, 2012). Using accelerometers to investigate the physical activity levels of individuals with intellectual disability, older adults with DS are spent less time in physical activity and more time in sedentary activity when comparing to older adults with intellectual disability (Dixon-Ibarra et al., 2013). People with DS are more likely to spend less time in MVPA than their counterparts.

Gait Patterns of Individuals with DS

The gait pattern of individuals with DS are different than individuals without DS. Parker, Bronks, and Snyder (1986) compared the walking pattern of 10 individuals with DS to individuals without disability using cinematographic analysis techniques and found that individuals with DS walked with less stability. In another study comparing 98 children with DS to 30 healthy children, there was an increase in hip flexion during the entire gait cycle, an increase in knee flexion during the stance phase, a decrease in knee range, a decrease in plantar flexion of the ankle at initial contact with the ground, and weaker ankle power amongst the children with DS (Galli, Rigoldi, Brunner, Virji-Babul, & Giorgio, 2008). In addition, children with DS show a significantly greater dynamic instability than their counterpart (Buzzi & Ulrich, 2004). During gait, when the legs are moving, children with DS had a higher chance for variability among each gait cycle (Black, Smith, Wu, & Ulrich, 2007; Buzzi & Ulrich, 2004). In other words, children with DS

are more likely to have different gait movements in each cycle. These results suggest that individuals with DS walk less efficiently. In another study, Cimolin and colleagues (2010) found that individuals with DS have a longer stance duration, reduced anterior step length and velocity of progression, a forward tilted pelvis in the sagittal plane, a plantar flexed position with a reduced range of motion, and significantly stiffer hips as compared to individuals without disability.

During walking activities, Individuals with DS also have been shown to have a higher energy cost than those without DS. A study by Agiovlasitis and colleagues (2009) investigated 14 adults with DS and found that the net rate of oxygen uptake and the net oxygen uptake per kilometer of walking were higher than 15 adults without DS. Results from this study also suggest that individuals with DS have a weaker walking economy and tend to walk slower than individuals without disability (Agiovlasitis, McCubbin, Widrick, et al., 2009).Overall, people with DS walk differently than people without DS.

As mentioned previsouly, indivdiuals with DS may have higher energy expenditure during walking and other physical activities. One possible reason for the increased energy expenditure during walking in individuals with DS may be due to their abnormal gait pattern (Agiovlasitis et al., 2011; Agiovlasitis, McCubbin, Yun, Widrick, & Pavol, 2015; Kubo & Ulrich, 2006). In a study comparing the motion of the center body mass of 15 adults with DS and 15 adults without DS, adults with DS had increased mediolateral motion compared to adults without DS (Agiovlasitis, McCubbin, Yun, et al., 2009). This variation in gait pattern is one way individuals with DS increase their stability during walking (Agiovlasitis et al., 2015). Walking with increased movements along the

mediolateral axis could increase energy expenditure (Ulrich, Haehl, Buzzi, Kubo, & Holt, 2004).

Higher energy expenditure during walking of individuals with DS can also be explained by other gait characteristics. In a recent study, Agiovlasitis and colleagues (2015) found that individuals with DS had less precise movement control and had greater difficulty maintaining stability due to poor balance and low muscle tone. In support of these findins, Smith and Ulrich (2008) found that adults with DS walk slower with shorter, wider strides and spend more time in both the stance and double support phase during gait. However, compared to adults without DS, people with DS have a similar amount of stride frequency and dimensionless frequency during gait (Smith & Ulrich, 2008). To accommodate for the lack of strength and poor balance, individuals with DS tend to walk at a slower speed with a decrease in step length and increase in the frequency of steps (Smith, Kubo, Black, Holt, & Ulrich, 2007). These walking accommodations increase the energy expenditure for individuals with DS when walking or engaging in other physical activities (Agiovlasitis et al., 2011; Agiovlasitis, Motl, Foley, & Fernhall, 2012). Ulrich, Haehl, Buzzi, Kubo, and Holt, (2004) reported two possibilities for the increased energy expenditure during gait for children with DS. First, they hypothesized that the reduced arch in the foot leads to a decrease in the spring-like activity during gait. This requires greater energy or angular impulse with each step to replace the energy lost at heel strike. Their second hypothesis was that some of the sagittal plane angular impulse generation is “lost” due to an increase in mediolateral motion in children with DS (walked with wider step), using more energy to replace “lost”

energy during gait (Ulrich et al., 2004). The strategies individuals with DS use to maintain stability during gait, such as shorter stride lengths, slower speed, more time spent in stance and double stance phase, are different than typically developed people of the same age, and interestingly, are also strategies used by older adults without DS (Latash, Wood, & Ulrich, 2008). Therefore, it has been suggested that the walking pattern of individuals with DS changes at a much rapid rate than their counterparts of the same age (Smith & Ulrich, 2008).

Motion Sensors

Over the last decade, there has been an increase in the usage of accelerometers in measuring physical activity levels (Rowlands, 2007). Accelerometers measure body movements in terms of acceleration (Reilly et al., 2008). These motion devices are small and compact with memory capacity to collect data or measure physical activity levels over a period of time (Rowlands, 2007). Currently, the most popular brand of accelerometer that measures physical activity is Actigraph, formerly known as the MTI, CSA, and the WAM accelerometers (Actigraph Inc., Pensacola, Florida; Rowlands, 2007; Troiano, 2005). The first model of the Actigraph accelerometer released was a uniaxial accelerometer. Uniaxial accelerometers measure acceleration along the vertical axis. Currently, most of the newer releases of Actigraph accelerometers are triaxial accelerometers. Unlike uniaxial accelerometers, which only measure acceleration in the horizontal plane, triaxial accelerometers can measure acceleration along all three-movement axes — vertical, anteroposterior, and mediolateral axis.

Accelerometers from Actigraph use the microelectromechanical systems (MEMS) and lithography technology to measure acceleration. Actigraph triaxial accelerometers measure acceleration ranging in magnitude from +6 to -6 gravity (g's; ActiGraph Inc., 2013). Uniaxial accelerometers from Actigraph use the same system but measure acceleration in smaller ranges (ActiGraph Inc., 2011). The MEMS work by creating surface charge between two fixed plates mounted next to each other. When the device experiences a change in acceleration, one of the fixed plates will move and create a surface charge. Using a twelve-bit analog to digital converter, the surface charge are converts into digital data to determine epoch ranges from 30 to 100 Hz (ActiGraph Inc., 2013). The data will pass through a digital filter between 0.25 and 2.5 Hz. The filter will disregard non-human movements by eliminating data that does not fall within the filter ranges. Initial signals for most accelerometers are bi-directional, meaning they can be both positive and negative (Chen & Bassett, 2005). Using an integration algorithm, that is unknown to the public, all signals become positive and are added together to produce accelerometer outputs (Chen & Bassett, 2005).

Accelerometer Outputs

Activity counts are output data of accelerometers (Chen & Bassett, 2005; Rowlands, 2007; Tryon & Williams, 1996). The counts are the accelerometer voltage/digital signals after being filtered and amplified (Chen & Bassett, 2005). Activity counts are unit less and arbitrary (Rowlands, 2007). It is difficult to interpret the meaning of activity counts. However, there is evidence that activity counts are proportional to the energy expended during body movements (Melanson & Freedson,

1996) and can be interpreted as a direct reflection of energy expenditure (Reilly et al., 2008). Higher activity counts correlate with higher intensity of physical activity, higher energy expenditure, and higher overall physical activity level. Uniaxial accelerometers provide activity counts along the vertical axis, as these accelerometers only measure along the vertical axis. Triaxial accelerometers provide activity counts from each of the three-movement axes, vertical, anteroposterior, and mediolateral axis, separately. It is interesting to note that activity counts between different models of accelereomters are not interchangeable. Due to the proprietary nature of data processing by different manufactures, different algorithms were used to determe activity counts for different models of accelerometers.

Vector magnitude (VM) is a proposal method to capture physical activity (Bouten et al., 1994). As described above, triaxial accelerometers provide three different sets of activity counts along the three movement axes (vertical, anterioposterior, and mediolateral axis activity counts). VM is derived from the sum of the activity counts from the 3 movement axes using the following equation,

$$VM = \sqrt{vertical^2 + mediolateral^2 + anterioposterior^2}$$

VM is determined from all three axes of accelerometer output and can be used to predict energy expenditure. VM identifies the intensity of energy expenditure.

Cut Points & Thresholds

To classify the intensity of physical activity and physical activity levels, cut points or intensity thresholds are used. Using cut points, each category of physical activity level can be determined. Cut points are derived from accelerometer outputs, activity counts,

or VM. The goal of cut points is to give biological meaning to accelerometer outputs (Rowlands, 2007). Using cut points, physical activity patterns, frequencies, and duration of each level of physical activity can be identified. Currently, many cut points are available and a lack of agreement exists between the different cut points (Trost, Loprinzi, Moore, & Pfeiffer, 2011). Disadvantages of using cut points are that certain cut points can only be apply to certain groups and certain age of individuals and cut points are not interchanable. Both uniaxial and triaxial accelerometers can utilize uniaxial cut points to determine physical activity levels. Triaxial accelerometer cut points typically use the output of VM, while uniaxial cut points are derived from vertical axis activity counts. Vertical axis cut points and VM cut points are different and are not interchangeable (Keadle, Shiroma, Freedson, & Lee, 2014).

The process of developing cut points is called calibration (Chen & Bassett, 2005) and is similar for both the uniaxial approach and triaxial approach. Calibration of cut points compares energy expenditure to accelerometer outputs. Using indirect calorimetry, energy expenditure can be estimated (Laporte, Montoye, & Caspersen, 1985). The activities that have been chosen for calibration range from simple walking to running at different speeds and activities represent various intensity levels of day-to-day activities of the target population across different intensity levels (Troiano, 2005). Currently, the two methods of determining cut points include using a linear regression algorithm and a receiver operating characteristic curve (Bassett, Rowlands, & Trost, 2012). The ranges of activity count and/or VM are matched to the energy expenditure or MET levels of sedentary, light, moderate, and vigorous intensity. For example, energy

expenditure of 0 to 1 MET is considered to be a sedentary activity (Norton, Norton, & Sadgrove, 2010). Therefore, accelerometer outputs of physical activity that fall between 0 to 1 MET will be the thresholds for identifying sedentary intensity levels of physical activity (Freedson, Melanson, & Sirard, 1998).

One of the first cut points developed for the uniaxial accelerometer for Actigraph and uniaxial approach is the cut point developed by Freedson and colleagues (1998). The cut point was based on data from 25 adult males and 25 adult females who performed 6 different treadmill activities at different speeds while wearing a uniaxial accelerometer with open circuit spirometry. Another example of cut point development by Santos-Lozano and colleagues (2013) utilized GT3X triaxial accelerometers and the VM or triaxial approach. Participants in the calibration were asked to perform 10 minutes of different activities, which included: 1) resting, treadmill walking and running at 3, 5, 7, and 9 km per hour and 2) repeated sitting-to-standing movements while wearing the triaxial accelerometer on the right hip. The study developed one cut point based on VM and one cut point based on vertical axis activity counts. Despite the data derived from the same model of accelerometer, the two cut points were different from each other.

Despite the availability of VM cut points, the most commonly used cut points among studies measuring physical activity levels are uniaxial cut points. More importantly, cut points developed from VM are different from cut points developed from vertical axis activity counts (Aguilar-Farías, Brown, & Peeters, 2014; Keadle et al., 2014).

Comparison of Uniaxial and Triaxial Approaches

It is inconclusive as to which approach for cut points - vertical axis cut points or VM cut points - are more accurate when measuring physical activity levels. There is evidence that suggests VM cut points and vertical axis cut points are similar when measuring MVPA (Howe, Staudenmayer, & Freedson, 2009; Robusto & Trost, 2012). Also, others have suggested VM cut points may be better predictors of energy expenditure during physical activities (Ott, Pate, Trost, Ward, & Saunders, 2000; Yamada et al., 2009).

It has been further suggested that VM cut points may be an better predictor of energy expenditure than vertical axis cut points across different categories of physical activity (Azevedo, Taylor, Innerd, & Batterham, n.d.; Santos-Lozano et al., 2013; Yamada et al., 2009). Ott and colleagues (2000) suggested triaxial accelerometer outputs (i.e., VM) had a higher correlation with predicted MET levels and heart rate than uniaxial accelerometer outputs (i.e., vertical axis activity counts) in 28 children between the ages of 9 to 11 years during free play. Despite the higher correlation in triaxial accelerometer outputs, the correlation in uniaxial accelerometer outputs was also significant. They found triaxial acceleroemters were significantly correlated with predicted MET levels ($r = 0.69$) and heart rate ($r = 0.73$), while uniaxial accelerometer had a lower correlation coefficient with predicted MET levels ($r = 0.43$) and heart rate ($r = 0.64$). Also, Fudge and colleagues (2007) showed that uniaxial accelerometer outputs plateaued and did not have a positive linear relationship with physical activity levels during high-intensity walking and running. Contrarily, triaxial accelerometer outputs continued to

demonstrate a positive linear relationship even during higher intensity walking and running.

However, Howe, Staudenmayer, and Freedson (2009) studied 212 individuals without disability performing activities of daily living and treadmill activities and reported that VM did not significantly improve the relationship between accelerometers and energy expenditure compared to vertical axis activity counts. Also according to Stec and Rawson (2012), in resistance training, accelerometer outputs from both uniaxial accelerometers and triaxial accelerometers share similar results in predicting energy expenditure. They concluded triaxial accelerometers and uniaxial accelerometers provide similar results when measuring resistance training. In addition, VM cut points developed by Costa, Barber, Cameron, and Clemes (2014) for children and the vertical axis cut points developed by Pate and colleagues (2006) and Trost and colleagues (2012) for children were all shown to classify physical activity levels accurately (Costa et al., 2014). This demonstrated that both uniaxial and triaxial approaches of cut points could be used to identify different categories of physical activity correctly. Also, the difference in accelerometer outputs between uniaxial and triaxial accelerometers does not impact the classification of categories of physical activity among individuals, where the relationship of triaxial accelerometer and uniaxial accelerometer with energy expenditure was not significantly difference with similar correlation with energy expenditure ($r = 0.89$, $p < 0.001$ for triaxial accelerometer and $r = 0.88$, $p < 0.001$ for uniaxial accelerometer; Hänggi, Phillips, & Rowlands, 2013). Kelly and colleagues (2013) reported VM and vertical axis activity counts had a similar correlation with oxygen

consumption (VO_2) during different speeds of treadmill exercise in 42 college age participants.

There is currently a paucity of research regarding which types of cut points are better for individuals with disabilities. Studies in the past have used the uniaxial approach of cut points measuring physical activity levels among individuals with disabilities (Phillips & Holland, 2011). For individuals with disabilities showing abnormal movements, using triaxial approach may be more appropriate since they could better capture their unique movements (Agiovlasitis, McCubbin, Yun, et al., 2009; Kubo & Ulrich, 2006). In regards to the usage of triaxial accelerometers for individuals with disabilities, a study by Oftedal, Bell, Davies, Ware, and Boyd (2014) found that for 51 ambulant toddlers with cerebral palsy, using triaxial accelerometers and VM cut points provided more accurate measures of sedentary activities than uniaxial cut points. The authors also suggested that uniaxial cut points are not recommended for people with disabilities.

Accelerometers and Individuals with Down syndrome

The usage of accelerometers in measuring physical activity levels can be applied to individuals with disabilities as well. Accelerometers have demonstrated validity in detecting movement in individuals with DS (Esposito, 2012). Using uniaxial accelerometers, the abnormal gait pattern of people with DS was detectable and the vertical axis activity counts were different between those with and without DS (Agiovlasitis et al., 2011). However, due to the unique traits of people with DS, the currently popular uniaxial approach of classifying physical activity levels may not be

appropriate, as they were designed and calibrated for people without disabilities (Agiovlasitis et al., 2012; Esposito, 2012). People with DS have demonstrated an altered relationship between METs and activity counts during walking when compared to people without DS (Agiovlasitis, Motl, et al., 2012). As walking speed increases, activity counts increase. However, people with DS show a disproportionately higher rate of energy expenditure as activity counts increase (Agiovlasitis et al., 2011; Agiovlasitis, Motl, et al., 2012). Because of this altered relationship, the currently available cut points are less accurate in predicting energy expenditure for people with DS (Agiovlasitis et al., 2011).

Another reason why current cut points may not be appropriate for individuals with DS is the lower VO_2 peaks associated with current cut points. Individuals with DS have been shown to have higher VO_2 usage in walking activities as compared to individuals without DS (Agiovlasitis et al., 2010). People with DS have an altered VO_2 to activity counts relationship with a higher rate of VO_2 during walking. Currently, available cut points are thought to underestimate MVPA and therefore should be higher for people with DS (Agiovlasitis et al., 2010).

Examining the Association between Overlapping Correlation

Overlapping correlation is defined as two correlation coefficients obtained from a single sample where the two correlations shared common variables (Meng, Rosenthal, & Rubin, 1992). Compared to traditional correlation coefficients (e.g. Pearson correlation coefficient), overlapping correlation needs an alternative approach when comparing different overlapping correlation due to the structure of overlapping

correlation violating the independence of measurement assumption under Classical Test Theory. Often, these overlapping correlation coefficients were compared to other correlation coefficients where they shared a common variable (Meng et al., 1992). The goal of comparing correlation coefficients is to determine differences in magnitudes of the two correlation coefficients. An overlapping correlation can be a long assessment and short assessment with the same dependent variable.

There are multiple ways in comparing overlapping correlations. Traditionally, using the method of Dunn and Clark (1969) transforming the correlation coefficients to Fisher's z-score is preferred. It had been shown that large sample sizes are required to obtain normal distribution for correlation coefficients (Silver & Dunlap, 1987), therefore, correlation coefficients are almost always skewed. Transforming the correlation coefficients into Fisher's z-score can overcome the problem of being skewed among correlation coefficient data. In fact, Fisher's z transformation almost entirely corrects the skew in the distribution of correlation coefficients (Silver & Dunlap, 1987) and it improved the normality for small sample sizes and extreme sample correlation (Meng et al., 1992).

Several problems have been reported when using the methods of comparing correlation coefficients by transforming data to Fisher's z score. One problem is the exceeding estimation of Type I error rate (Silver & Dunlap, 1987). After transforming the raw correlation coefficients into z score, a z test is used to continue the comparison between the correlation coefficients. However, May and Hittner (1997) demonstrated that the t tests of comparing correlation maintained statistical power at the expense of

an inflated Type I error rate. This notion was further confirmed by Hittner, May, and Silver (2003) when evaluating different methods of comparing correlation. Another problem is the long and complex process of transforming the correlation coefficients into z scores. To compare correlation, it required researched to transform the correlation coefficients into z scores then used a t test to complete the analysis.

To overcome the problems of transforming correlation coefficients into z scores when comparing overlapping correlations, Meng, Rosenthal, and Rubin (1992) proposed a more simplified approach. This approach targeted the comparison of overlapping correlation. The following equation was developed by Meng and colleagues (1992) to compare correlation.

$$Z = (z_{r1} - z_{r2}) \sqrt{\frac{N-3}{2\,(1 - r_x)h}}$$

Where N is the number of subjects, z_{r1} is the Fisher z transformed $r_i = r_{xy}$, r_x is the correlation between the two predictor variables of X_1 and X_2. This approach also has a better control of Type I error rate than other approaches (Hittner et al., 2003). It considers the correlation between the non-share variable when comparing overlapping correlation and has been tested for identifying heterogeneity of correlation and testing a contrast among overlapping correlation. Meng's z - test has advantages in comparing overlapping correlation and has also been used in practice in the psychology field (Duckworth & Seligman, 2005; Kühn, Gleich, Lorenz, Lindenberger, & Gallinat, 2014).

Chapter. 3 Methods

Participants

A total of 38 individuals were recruited to participate in the study, including 19 individuals with DS (DS) from physical activity programs and/or community living organizations in Pacific Northwest and 19 aged- and gender- matched participants without DS (nDS) from the community. Participants in the nDS group were recruited by targeting individuals with similar age (within 3 years), and sex to the sample of participants with DS. One participant with DS withdrew from the study and did not complete the study protocol, resulting in 18 participants with DS completing the testing protocol in its entirty. All individuals with DS were diagnosed with Trisomy 21 DS (10 females) and aged between 19 to 64 years (mean = 32.6, *SD* = 14.2).

All participants were over the ages of 18 years old and able to walk independently without assistive devices (i.e. cane, crutch, walker, or wheelchair). On average, the two groups had similar age (DS: 32.56 $\pm$ 14.16; nDS: 31.61 $\pm$ 12.90 years). Compared to the nDS group, individuals with DS had shorter height (DS: 147.52 $\pm$ 6.78; nDS: 169.25 $\pm$ 9.72 cm) and higher BMI (DS: 29.6 $\pm$ 8.11; nDS: 26.23 $\pm$ 5.50 kg/cm^2). Females in the DS group have a higher BMI than male in the DS group, while females in the nDS group have a lower BMI than the male in the nDS group (see Table 1 for summary of participant demographics). Written informed consent was obtained from all participants and the legal guardians of participants with DS. Testing procedures were approved by the Institutional Review Board at Oregon State University.

Table 1. Demographic Information of All Participants

Group	Sex	Age	Height (cm)	Weight (kg)	BMI (kg/cm^2)
DS	Male (*n = 8*)	33.5 ± 16.19	153.30 ± 2.79	63.06 ± 8.07	26.79 ± 3.56
	Female (*n = 10*)	31.8 ± 13.18	142.89 ± 5.22	65.95 ± 21.41	31.85 ± 10.09
	Total (*n = 18*)	32.56 ± 14.16	147.52 ± 6.78	64.67 ± 16.49	29.6 ± 8.11
nDS	Male (*n = 8*)	31.75 ± 14.29	174.58 ± 9.71	97.90 ± 20.81	28.71 ± 5.77
	Female (*n = 11*)	31.27 ± 11.85	165.37 ± 8.06	67.49 ± 16.15	24.42 ± 4.76
	Total (*n = 19*)	31.61 ± 12.90	169.25 ± 9.72	76.08 ± 20.51	26.23 ± 5.50
Total	*N = 37*	31.9 ± 12.8	158.7 ± 13.8	70.53 ± 19.29	27.9 ± 7.0

Note: Results are presented as mean ± *SD* for each variable.

Instrument

GT3X+ accelerometer (Actigraph Inc., Pensacola, FL) is a triaxial accelerometer that measures acceleration along the vertical, anteroposterior, and mediolateral axis. It is one of the most commonly used accelerometer to measure physical activity levels in recent years (Aadland & Ylvisåker, 2015). GT3X+ accelerometer weights 19 g with the dimensions of 4.6 cm x 3.3 cm x 1.5 cm. The device can assess accelerations ranging between -6 to 6 g with the frequency ranging from 0.25 Hz to 2.5 Hz. The micro–electro–mechanical accelerometers system (MEMS) inside the accelerometer can detect the direction of the acceleration. The outputs of the accelerometer are sampled by a 12 – bit Analog to Digital Convertor (ActiGraph Inc., 2013). The outputs include vertical axis activity counts, anteroposterior axis activity counts, and mediolateral axis activity counts. All participants wore the accelerometer on their right hip and was secured by an

elastic waistband. The sampling rate of the accelerometer for this study was set at 100 Hz and the data was measured at a one second epoch.

Oxygen consumption (VO_2) was measured using a portable metabolic system, Oxycon Mobile (Yorba Linda, CA). It measures on a breath – by – breath basis to estimate energy expenditure based on gas exchange. The Oxycon Mobile is a lightweight system weighing at 800 g, and is worn on the front of the body. Along with the portable metabolic system, a flexible face mask (Hans Rudolph, Kansas City, MO) is connected to the unit and placed over the participants' mouth and nose. A bidirectional rotary flow, a measurement sensor (Triple V), and a sampling line were attached to the mask from the system to measure the volume of inspired and expired air. The Triple V sensor connected to the analyzer unit of the system determined the O_2 and CO_2 content of each breath. Prior to data collection of each participant, the system was calibrated as instructed by the manufacturers' instructions with known gas composition. The system was placed on the front of the body using a harness and the mask was secured by an elastic waistband by each participant. Additionally, a heart rate monitor (Polar Electro, Kempele, Finland) was paired with the metabolic system. The heart rate monitor was used as an indicator for approximate relative intensity. Oxycon Mobile provided a valid measure of oxygen uptake over a variety of physical activity intensities with differences between absolute and predicted values ranging from 1.3% to 2.6% (Rosdahl, Gullstrand, Salier-Eriksson, Johansson, & Schantz, 2010).

Testing Protocol

All participants engaged in one testing session of 45 minutes with an additional five to twenty minutes of familiarization procedure when needed to help individuals become familiar with testing protocol. All participants were instructed to avoid food and exercise for at least 3 hours prior to data collection. Upon arrival, height and weight of each participant were measured to the nearest tenth cm and kg. All participants then watched an introductory video, 5 minutes in duration, introducing the purpose, the equipment used in the study, and the testing protocol of the study. All participants were given the opportunity to become familiar with the testing protocols and equipment. Four participants with DS, feeling uncomfortable with the equipment and/or research protocol, participated in the familiarization process. The familiarization process included allowing participants to wear the mask without connecting to the portable metabolic system and practicing the testing protocol along with the researchers. Depending on the comfort levels, familiarization process lasted between five to twenty minutes. It is important to note that task familiarization plays an crucial role in research assessment with participants with DS because of its ability to vastly improve the quality of data and compliance levels (Rintala, McCubbin, & Dunn, 1995).

All testing was completed on a large hard surface area. After equipped with all the instruments, participants sat quietly for ten minutes to bring physiologic function to resting levels and to collect resting metabolic rate. After the resting period, all participants took part in three different walking trials. Each walking trial lasted for six minutes and was conducted at three different speeds. The three different speeds of the

walking trials were, in order, self-selected speed, slow speed (2 mph), and fast speed (4 mph). Participants took part in each walking speed once with a five minute break in between each speed trial by sitting quietly and returning to resting metabolic state. During all walking trials, all participants walked in a figure "8" shape between 4 cones (see *Figure 1*). The diameter between 2 diagonal cones was 10 meters. The parameter of the rectangle ranged from 10 to 14 meters.

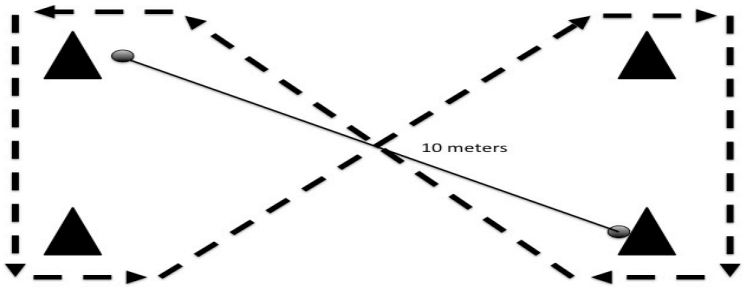

Figure 1. Walking Route of Walking Trials

During the first walking trial of self-selected speed, participants walked at their preferred speed. Their speed was measured by a set of photoeye emitters (Lafayette Instrument Company, Lafayette, IN) that was placed at meter three and meter seven of the diameter of the rectangle. For the two walking trials of slow (2 mph) and fast trials (4 mph), a trained pacer, along with a calibrated measuring wheel with CatEye speedometer (CatEye, Kuwazu, Japan) walked in front of the participants. Participants followed the trained pacer and maintained speed. Throughout each trial, researchers verbally encouraged and provided simple verbal instruction to each participant to

ensure participants met the selected walking speeds and followed the walking route. A similar protocol had been used to measure the accuracy of pedometers among individuals with DS (Agiovlasitis et al., 2010; Pitchford & Yun, 2010) and individuals using a wheelchair (Learmonth, Kinnett-Hopkins, Rice, Dysterheft, & Motl, 2015).

Data Reduction

A total of 18 participants in the DS group were included for the analysis. All participants in the nDS group (*n = 19*) were included in the analysis. For all trials, only the data between minutes 3:45 and minutes 5:45 of the six minute were included in data analysis due to the unstable metabolic rate at the beginning and at the end of each trial. Accelerometer outputs of activity counts from each of the three axes and VM were downloaded using the specific program at an epoch of 1 second. VO_2/kg (mL/min/kg), a marker for energy expenditure, of each walk trials were downloaded breath by breath from the portable metabolic system using the specific program.

In order to match the data between the accelerometer and portable metabolic system, data from both devices for each participant between 3:45 and 5:45 of each trial were averaged over each two minute period for each walking trials. Each participant had an average vertical axis activity count for each walking trial, average VM for each walking trial, and average energy expenditure for each walking trial. Two correlation coefficients were determined at the group levels between energy expenditure, VO_2/kg, and activity counts from the vertical axis, and between energy expenditure and accelerometer outputs of VM with all walking trials included. The correlation coefficients were determined using the linear mixed effect ts models (Hamlett, Ryan, &

Wolfiner, 2004), while properly accounting for the data's replicate structure (Hamlett, Ryan, Serrano-Trespalacios, & Wolfinger, 2003). Please see Appendix E Section C to see the statistical comments for determining correlation coefficients between variables. This approach was used because of the structure of data (i.e. data were nested within each person). A similar approach was used in a study by Hänggi, Phillips, and Rowlands (2013) with the overall purpose of comparing correlation coefficients.

Statistical Analysis

The mean age, weight, height, BMI were calculated for both the DS and nDS group. Activity counts, VM, and emergy expenditure were compared between the two groups using a t test. The average speed during the self-selected speed trial and the average activity counts from accelerometers of each walking trial were both calculated. To determine which accelerometer outputs can better-predicte energy expenditure, Meng's z test was used (Meng, Rosenthal, & Rubin, 1992). Meng's z test was developed to compare overlapping correlation. Due to the nature of data structure, where the data are nested within each participant, the data violated the independence assumption of Classical Test Theory. When comparing overlapping correlation, the statistical analysis needs to consider the common variables. Meng's z test is a method for comparing correlation coefficients between a shared variables and a set of independent variables or overlapping correlation. The test requires the transformation of the correlation into Fisher z scores and take into the association between the independent variables, in this study, vertical axis activity coutns and VM. Meng's z test overcomes the bias and the skewness of the data in overlapping correlation (Hittner, May, & Silver, 2003; Wilcox &

Tian, 2008). Meng's z test has been used in other studies comparing correlation within group levels (Duckworth & Seligman, 2005; May & Hittner, 1997). Hänggi, Phillips, and Rowlands (2013) used the same method in comparing the overlapping correlation between accelerometer outputs and energy expenditure in 49 children. The correlation coefficients between energy expenditure and activity counts from vertical axis were compared to the correlation coefficient between energy expenditure and accelerometer outputs of VM in the DS and the nDS group using Meng's z test (please see Appendix E Section D for statistical command). In addition, a z-test was used to determine the difference in correlation coefficients between the DS and the nDS groups. All analysis was conducted on RStudio Version 1.0 (RStudio, Inc., Boston MA). Please see appendix E for statistical commands of Meng's z test (Section D) and z test (Section E) of the data analysis.

Ch4. Results

During the self-selected speed trial, the average speed of the sample was 2.50 ± 0.67 mph. The DS group walked at an average speed of 2.02 mph, which was slower than the nDS group of 2.95 mph. Table 2 shows the average speed of each group during the self-selected speed trial.

Table 2. Average Speed during Self-Selected Speed Trial of each Group

Group	Speed during Self-Selected Speed Trial (mph)
DS	2.02 ± 0.44
nDS	2.95 ± 0.51
Total	2.50 ± 0.67

Note: Results are presented as mean ± *SD* for each variable.

The nDS group had a higher activity count in both vertical axis and anteroposterior axis than the DS group based on raw values but not in mediolateral axis. In regards to the accelerometer output of VM, the nDS group had higher output than the DS group based on raw values. During the self-selected speed trial, the nDS group and the DS group exhorted similar amount of energy, 11.79 mL/min/kg and 11.23 mL/min/kg, respectively. The DS group had a higher energy expenditure during the slow walk trial with 10.85 mL/min/kg than the nDS group with 8.80 mL/min/kg. Both groups follow the trend of higher energy expenditure and higher accelerometer outputs as speed increases. Table 3, 4, and 5 show the accelerometer outputs and energy expenditure of all three walking trials.

Table 3. Group Averages for Accelerometer Outputs and Energy Expenditure of Self-Selected Speed Walking Trials of each Group

Group	Vertical	AP[a]	ML[b]	VM	VO_2/kg[c]
DS	1756.06 ± 699.35*	1867.97 ± 751.26	2375.25 ± 758.22	3550.21 ± 1108.26	11.23 ± 2.75
nDS	2894.03 ± 1092.43*	2060.13 ± 659.41	1783.39 ± 825.41	4051.84 ± 1308.59	11.79 ± 2.81
Total	2340.42 ± 1077.11	1966.65 ± 719.58	2071.32 ± 837.90	3807.80 ± 1255.08	11.52 ± 2.76

Note: Results are presented as mean ± *SD* for each variable as activity counts for vertical, anteroposterior, and mediolateral axis.

[a] Anteroposterior axis

[b] Mediolateral axis

[c] Results are presented as mean ± *SD* for the variable in the unit of mL/min/kg

* $p < 0.05$ for significant difference between the two groups

Table 4. Group Averages for Accelerometer Outputs and Energy Expenditure of Slow Speed Walking Trials of each Group

Group	Vertical	AP[a]	ML[b]	VM	VO_2/kg[c]
DS	1626.53 ± 592.08	1575.50 ± 578.13	2193.31 ± 745.83	3211.50 ± 923.50	10.85 ± 1.82*
nDS	1619.63 ± 359.36	1530.76 ± 465.76	1625.29 ± 764.34	2845.04 ± 651.78	8.80 ± 1.64*
Total	1622.9865 ± 479.71	1552.53 ± 516.54	1901.62 ± 798.52	3023.32 ± 805.99	9.80 ± 1.99

Note: Results are presented as mean ± *SD* for each variable as activity counts for vertical, anteroposterior, and mediolateral axis.

[a] Anteroposterior axis

[b] Mediolateral axis

[c] Results are presented as mean ± *SD* for the variable in the unit of mL/min/kg

* $p < 0.05$ for significant difference between variables

Table 5. Group Averages for Accelerometer Outputs[a] and Energy Expenditure[b] of Fast Speed Walking Trials of each Group

Group	Vertical	AP[a]	ML[b]	VM	VO_2/kg[c]
DS	2779.97 ± 1034.46*	2374.53 ± 1055.30	2858.72 ± 1192.12	4755.53 ± 1575.86	15.75 ± 4.10
nDS	3872.55 ± 1046.78*	2867.74 ± 879.51	2345.26 ± 1250.12	5493.88 ± 1392.47	16.66 ± 3.28
Total	3341.03 ± 1166.06	2627.80 ± 987.48	2595.05 ± 1232.96	5134.68 ± 1510.68	16.22 ± 3.68

Note: Results are presented as mean ± *SD* for each variable as activity counts for vertical, anteroposterior, and mediolateral axis.
[a] Anteroposterior axis
[b] Mediolateral axis
[c] Results are presented as mean ± *SD* for the variable in the unit of mL/min/kg
* $p < 0.05$ for significant difference between the two gruops

The correlation coefficients between energy expenditure (VO_2/kg) and the activity outputs of both the vertical axis and VM were determined using the mixed design method. The correlation ranged from 0.53 to 0.75, suggesting a moderate correlation between accelerometer outputs and energy expenditure for both groups. The raw correlation coefficients were higher in the nDS with all accelerometer outputs. Table 6 shows the correlation coefficients between accelerometer outputs and energy expenditure of the different groups.

Table 6. Correlations Coefficients between Accelerometer Outputs and Energy Expenditure, VO_2/kg (mL/min/kg)

Group	Vertical	VM
DS	0.53	0.64
nDS	0.75	0.75
Total	0.62	0.70

Note: Values are correlation between energy expenditure (VO_2/kg) and accelerometer outputs and vertical is for vertical axis activity counts.

Meng's z test was used to determine the difference between the correlation coefficient within the group. The Meng's z-test suggests that there is no statistical difference in correlations between the vertical axis and VM in the nDS group with VO_2/kg ($z = -1.71$, $p = 0.85$). There is also no statistical difference in correlation with energy expenditure between accelerometer counts from the vertical axis and accelerometer outputs of VM for the DS group ($z = -1.71$ and $p = 0.086$). Table 7 shows the z-score and p-value comparing within the group using the approach developed by Meng and colleagues (1992).

Table 7. Comparison of Correlation Coefficients Within Group and Between Group

	z - score	p - value
Within Group		
nDS	-1.71	0.85
DS	0.14	0.086
Between Group		
Vertical	1.99*	0.046
VM	1.06	0.29

Note: Values are z statistics corresponding to each comparison and vertical is for vertical axis activity counts.

* $p < 0.05$ for significant difference between variables

To compare correlations between groups, z-test was used. There was a significant difference in correlation coefficients with energy expenditure and vertical axis activity counts between DS group and the nDS group (z = 1.99, p = 0.046) according to the z-test. There was no statistical difference between the correlation of energy expenditure and VM between the two groups using accelerometer output of VM (z = 1.06, p = 0.29). The results of the z-test are shown in Table 7.

Ch. 5 Discussion

The purpose of the study was to investigate the accuracy of accelerometer output among individuals with and without DS in estimating energy expenditure. The results showed the correlation between energy expenditure and accelerometer outputs, for both vertical axis activity counts and VM, in individuals without DS are 0.75. For people with DS, the correlation coefficient between energy expenditure and accelerometer outputs are lower than their counterparts of similar age. The correlation efficient between energy expenditure and accelerometer outputs, vertical axis activity counts and VM, for people with DS are 0.53 and 0.64, respectively. Despite differences in the raw value of the correlation coefficient, there was no statistical differences found between correlation coefficients in energy expenditure between the two outputs.

Although there is inclusive results on the strength of relationship between accelerometer outputs and energy expenditure for people with DS, the results of this study aligned with previous studies suggesting the VM may not be necessary better than vertical axis activity count for people without DS when measuring physical activity levels (Hänggi et al., 2013; Howe et al., 2009). Our results indicated that using either approach in estimating energy expenditure and physical activity levels will yield similar results for people without DS.

Overall, these findings may not be too surprising, considering characteristics of gait. According to the six determinants of gait theory (Saunders, Inman, & Eberhart, 1953), six different kinematic features help reduce the displacement of the body center of mass. Moving the center of mass vertically or horizontally will increase the energy

cost during gait (Saunders et al., 1953). The six kinematic features or determinants are: 1) pelvic rotation, 2) pelvic tilt, 3) knee flexion after heel strike in the stance phase, 4) foot and ankle motion, 5) knee motion, and 6) lateral displacement of the pelvis. The human body uses these features to increase efficiency and decrease energy expenditure during walking. Without any variations, unlike people with DS, individuals without DS use these strategies to maintain their center of mass in mostly the horizontal plane and move along the horizontal plane. People without DS move along the horizontal plane during gait to maintain efficiency with the six strategies, therefore, most movements during gait cycle recorded by the accelerometers will be along one plane. Using uniaxial approach or triaxial approach will yield similar results because gait activity us along one movement plane.

It was a surprise to see the results of the analysis comparing the magnitude of correlation coefficient with energy expenditure between vertical axis activity counts and VM for the DS group. While there were differences between the two correlation coefficients in raw values, there was no statistical difference. It was expected there to be differences between the correlation coefficients. It is difficult to conclude which approach of accelerometer outputs can better predict physical activity levels for individuals with DS due to the complexity of the issues. There is an alter relationship between energy expenditure and activity counts during gait among people with DS when comparing to their counterparts, where activity counts are less accurate in predicting energy expenditure for people with DS (Agiovlasitis, Beets, Motl, & Fernhall, 2012; Agiovlasitis, McCubbin, Yun, et al., 2009). This alter relationship could be

influenced by the unique characteristics of individual with DS, such as less stability during gait (Agiovlasitis, McCubbin, Yun, et al., 2009), high variability in physiological functions (Bull & the Committee on Genetics, 2011), altered cardiac function leading to lower physical fitness (Fernhall et al., 2009), and increased movements along the mediolateral axis during gait (Kubo & Ulrich, 2006).

The results of this study differ from current literature regarding the energy expenditure and accelerometer outputs. In an investigation by Agiovlasitis et al. (2009) analyzing the walking patterns of adults with and without DS across different speeds, they found adults with DS had increased variability of movements along the mediolateral axis compare to their counterparts. However, the center of mass along the vertical and anteroposterior axis did not differ between individuals with and without DS (Agiovlasitis, McCubbin, Yun, et al., 2009). In addition, Ulrich, Haehl, Buzzi, Kubo, and Holt (2004) studied the muscular structure of preadolescents with DS during gait pattern and found that people with DS had a higher energy cost when compared to their counterparts. Both studies suggested that the higher energy cost during gait exhibited by people with DS was due to the increased movements and variabilities of movements along the mediolateral axis. As showed in the data, the DS group had higher activity counts along the mediolateral axis than the nDS group, supporting that increased movements along the axis are exhibited by people with DS. Activity counts are proportional to energy expenditure (Melanson & Freedson, 1996) and VM is considered to be the summary of activity counts from the three movement axis. Hence, we expected VM should have a higher or different correlation coefficient with energy

expenditure than the correlation between vertical axis activity counts and energy expenditure among individuals with DS.

One possibility for these unexpected result is that the sensitivity of accelerometers in detecting movements for people with disabilities, inclucing people with DS. It might influence the results of the data for the DS group. Studies often found accelerometers underestimate energy expenditure during light intensity physical activity (Calabro, Lee, Saint-Maurice, Yoo, & Welk, 2014; Wetten, Batterham, Tan, & Tapsell, 2014). Calabro and colleagues (2014) found that GT3X accelerometers underestimates total energy expenditure during light physical activity and exercise, such as walking and unstructured activities, by 25.5%. It is interesting to note that when using piezoelectric technology to capture movements or estimate physical activity levels, there is a higher error rate among individuals with DS during slower speed walk (Agiovlasitis, Beets, Lamberth, Pitetti, & Fernhall, 2016). When comparing the accuracy of piezoelectric pedometer between people with and without DS, Pitchford and Yun (2010) found significant differences in absolute percent error in measuring steps between adults with and without DS with absolute percent error ranged 7.57% to 8.02% for adults with DS and 1.06% to 2.96% for adults without DS. This suggests that using piezoelectric motion sensor, including accelerometers and pedometers, might underestimate energy expenditure for individuals with DS. Despite these reports of low sensitivity to low intensity physical activity, the activity counts presented in the data suggested that piezoelectric accelerometers (GT3X+) were detecting movements along all movement

axes. This indicates that the low sensitivity of accelerometer might not be a limiting factor.

Another possibility is that our approach to determining VM possibly contributed to the results of this study. To determine VM, the equation of $\sqrt{x^2 + y^2 + z^2}$ was used. The observation represented the starting and ending position in three dimensional spacing. It does not consider the movements that occurred between the starting and ending positions. The increase in energy expenditure might not be represented in VM during movements for people with DS. Further, Bouten, Westerterp, Verduin, and Janssen (1994) investigated the contribution of accelerometer outputs from the three movement axes in estimating energy expenditure during movements. They hypothesized that the relationship between accelerometer outputs and energy expenditure are quadratic rather than linear. However, they found that linear regression of summation from accelerometer outputs in all three movements axes can better predict energy expenditure than the quadratic model. Individuals with DS do not have the same movement patterns as their counterparts and have higher energy expenditure and altered relationship with accelerometer output (Agiovlasitis et al., 2012). Individuals with DS have increased variation during movements (Agiovlasitis et al., 2009; Bull & the Committee on Genetics, 2011; Fernhall et al., 2009; Kubo & Ulrich, 2006). Therefore, the current approach of using linear relationship to determine VM might not be appropriate for people with DS.

To the authors' knowledge, this is the first study to compare the relationship of different type of accelerometer outputs and energy expenditure for people with DS.

Despite all these known challenges of using the accelerometer to measure physical activity levels for people with DS, the true reasons for less accuracy of VM and vertical axis activity counts requires further research. Additonal studies can investigate the use of multiple measurements to estimate physical activity levels among people with DS. Placing accelerometers at the waist, ankle, and the wrist at the same time could possibly increase the accuracy of accelerometers in measuring physical activity levels by assessing movements at multiple locations of body (Cleland et al., 2013; Gao, Bourke, & Nelson, 2012; He et al., 2014). Also, when developing cut points, it would be useful to take into account heart rate or using heart rate as criteria to further improve the accuracy of existing cut points (Coleman, Saelens, Wiedrich-Smith, Finn, & Epstein, 1997; P. M. Esposito, 2012). Recently, several researchers have recommended the use of both objective methods of accelerometers and subjective methods at the same time when measuring physical activity levels for people with a disability, including DS, could be beneficial (Izquierdo-Gomez et al., 2015; Krüger et al., 2017; Yu et al., 2015). Physical activity is multidimensional so no single assessment method can capture all subcomponents and domains in the activity of interest (Butte et al., 2012; Warren et al., 2010). Using subjective methods such as diary and activity logs could help identify the type of physical activities individuals with disability engage in. It might be inappropriate to determine the relationship between health and physical activity, if physical activity is only measured as a unidimensional construct. Despite all these different ways of measuring physical activity levels, further research and continued research are needed to determine the validity and feasibility of these measurements for people with DS.

When people with DS and without DS engage in the same speed of walking, their energy expenditure and accelerometer outputs are different. During the slow speed trial of 2 mph, people with DS exhibited higher energy expenditure than their counterparts. The average energy expenditure of the slow speed trials was 10.85 mL/kg/min for the DS group and 8.80 mL/kg/min for the nDS group, where the differences between the two groups was significant. Besides differences in energy expenditure, there are also differences in vertical axis counts between the groups. The nDS group accumulated an average of 3872.55 counts/min, while the DS had 2779.97 counts/min from the vertical axis during the slow speed trials. These differences had been reported by Agiovlasitis et al. (2011) as well. Because of these differences between individuals with and without DS when using vertical axis activity counts cut points, there should be separate cut points for people with DS and people without DS. Currently, to the author's knowledge, there is only one uniaxial cut points designed for people with DS by Agiovlasitis, Motl, Foley, and Fernhall (2012).

The correlation coefficient between energy expenditure and accelerometer is 0.53 for vertical axis activity counts and 0.64 for VM for people with DS and 0.75 for both approaches of accelerometer outputs for people without DS. It is unknown whether this is a sufficient correlation coefficient to determine if accelerometers are a valid tool in estimating physical activity levels. Currently, there is no shared standard for what is considered a "good" correlation coefficient for evaluating accelerometers. This is one of the great challenges for measurement (Adcock & Collier, 2001). Other validation studies have found the correlation coefficients with energy expenditure and uniaxial

approach of accelerometer outputs ranges from 0.50 to 0.87 for various age groups and individuals (Eston, Rowlands, & Ingledew, 1998; Hall, Howe, Rana, Martin, & Morey, 2013; Hänggi et al., 2013; Herman Hansen et al., 2014; Kelly et al., 2013; O'Neil et al., 2016; Ott et al., 2000; Sallis et al., 2000; Sandroff, Motl, & Suh, 2004; Santos-Lozano et al., 2013; Treuth et al., 2004; Trost, Pate, Freedson, Sallis, & Taylor, 2000). Despite these differences in correlation coefficients, each study claims the approach of accelerometer outputs of vertical axis activity counts or VM to be a valid measurement of energy expenditure and physical activity levels. Clearly, there is a need to construct a shared standard of validation for correlation coefficients.

Although this study is the first of its kind to examine the association between uniaxial approach and triaxial approach of accelerometer outputs and energy expenditure of people with DS, a few limitations should be considered. First, due to the prevalence of DS, the small sample size may have influenced the results of the study. A small sample size can lead to a lack of generalizability of the results. Second, this study only focuses on the activities of walking. Current studies have shown that the only activity in which individuals with DS demonstrated a mediolateral sway is walking. However, multiple studies have shown walking as one of the most common forms of physical activity for individuals with DS (Draheim et al., 2002; H. Stanish & Draheim, 2005). Finally, participants of this study only engaged in light and moderate intensity of physical activity. Individuals with DS might have a difficult time in performing higher intensity levels of physical activity for a prolonged period of time, depending on their physical fitness levels and familiarity of protocols.

Based on the conclusions of previous studies and the results of this study, it is difficult to conclude the validity of accelerometer in measuring physical activity levels for individuals with DS. The study had suggested that accelerometers might not be an appropriate measurement tools for physical activity levels among people with DS. Whitt-Glover, O'Neill, and Stettler (2006) investigated the physical activity patterns of children with DS and their similar age without disability siblings using accelerometers and found them to have similar physical activity patterns but the children with DS spending less time in vigorous physical activity. The authors conclude that accelerometry might over- or under- estimate energy expenditure for people with DS. Therefore, future research needs to build upon previous studies and continue to focus on the validity of accelerometer outputs in predicting energy expenditure and physical activity levels of people with DS accounting for their unique gait patterns and characteristic.

Chapter 6. Conclusion

In summary, it is inconclusive to determine which accelerometer approaches, vertical axis activity counts and VM, can better estimate physical activity levels for people with DS. Findings indicate that using both approaches will yield similar results for people without DS. Based on the present study's results, it is not clear whether vertical axis activity counts or VM will yield similar results in physical activity levels for people with DS due to the unique movements characteristics exhibited by individuals with DS. When using accelerometers in measuring physical activity levels of individuals with DS, caution should be made when interpreting the results based on accelerometer outputs. There is a need for further exploration of the accuracy and validity of accelerometers and accelerometer outputs for people with DS regarding physical activity and energy expenditure.

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APPENDICES

Appendix A: Study Advertisement

Volunteers Needed to Participate in study title:

~ Validity of Accelerometer in Individuals with and without Down syndrome ~

We are investigating the accuracy of accelerometers in measuring physical activity levels in people with and without Down syndrome using indirect calorimetry across different walking speeds. Your participation will aid in improving assessment of physical activity for people with and without Down syndrome.

Group 1: Diagnosis of Down syndrome, over 18 years old, and can walk without assistive devices

Group 2: No diagnosis of disabilities, over 18 years old, and can walk without assistive devices

IF YOU ARE INTERESTED OR HAVE ANY QUESTIONS:
Please contact the research team at:
leungc@oregonstate.edu
(541) 737 – 6919

Please visit the follow link for video:
https://youtu.be/A1u3SsSomh0

PI: Joonkoo Yun, jk.yun@oregonstate.edu

Oregon State University OSU

Appendix B: Demographic Questionnaire

Demographic Questionnaires

ID: _____ Date: _____

Please answer the follow questions:

1) Are you over the ages of 18 years?

☐Yes ☐No

How old are you? _____

2) Do you have a confirm diagnosis of any types of disabilities (physically, intellectual, and developmental)?

□ Yes □ No

3) Can you walk without using assistive devices (i.e. wheelchair, walker, cane, crutches, and etc.) for 6 minutes?

□ Yes □ No

PI: Joonkoo Yun, jk.yun@oregonstate.edu

Oregon State UNIVERSITY
College of Public Health and Human Sciences

Demographic Questionnaires

ID: _____ Date: _____

Please answer the follow questions by the participants' parent/care giver:

1) Is the participant over the ages of 18 years?

☐Yes ☐No

How old are the participants? _____

2) Did the participant of this study have a confirm diagnosis of Down syndrome?

□ Yes □ No

If, yes. What type? □ Trisomy 21 □ Translocation ☐Mosaic ☐Unknown

3) Can the participants walk without using assistive devices (i.e. wheelchair, walker, cane, crutches, and etc.) for 6 minutes?

□ Yes □ No

PI: Joonkoo Yun, jk.yun@oregonstate.edu

Oregon State UNIVERSITY
College of Public Health and Human Sciences

Appendix C: Data Collection Sheet

Data Collection

ID: _____ Date: _____

Height: _____ cm

Weight: _____ lbs

DOB: _____

Task (Duration)	Start Time	End Time	Starting Min	Ending Min
Rest (10)			0	10
Self-Selected Walk (6)			10	16
Rest (5)			16	21
Slow Walk (6)			21	27
Rest (5)			27	32
Fast Walk (6)			32	38

Self-Selected Walk Timing – 637.54 cm (Speed: _____ cm/s)

Lap Number	Time (sec)	Lap Number	Time (sec)	Lap Number	Time (sec)
1		7		13	
2		8		14	
3		9		15	
4		10		16	
5		11		17	
6		12		18	

Appendix D: Consent Forms

College of Public Health and Human Sciences
School of Biological and Population Health Sciences
Kinesiology Program
Oregon State University, 203C Women's building, Corvallis, Oregon 97331
Tel 541-737-8584 | Fax 541-737-6613

CONSENT FORM

Project Title:	Validity of Accelerometer in Individuals with and without Down syndrome
Principal Investigator:	Joonkoo Yun
Student Researcher:	Chun (Willie) Leung
Co-Investigator(s):	John Schuna Jr.
Sponsor:	
Version Date:	03/17/2016

I understand the following:

1. I am being asked to take part in a study to test step counters.

2. I am being asked to attend 1 to 2 testing sessions between 60 to 90 minutes long.

3. I will not eat or engage in any exercise 3 hours before taking part in this research study on day(s) of testing.

4. During the testing session, my weight and height will be measure.

5. I will be wearing a portable metabolic system over my body, a step counter on my right hip, a heart rate monitor over my chest, and a mask that will cover my mouth and nose.

6. I will be walking in a figure "8" shape between 4 cones.

7. I will be walking for total of 18 minutes. Every 6 minutes I will rest for 5 minutes by sitting in a chair.

8. I will be walking by myself for 6 minutes.

9. I will be walking at slow pace accompany by a research staff for 6 minutes.

10. I will be walking at fast pace accompany by a research staff for 6 minutes.

11. I can stop taking part in the study at anytime if I want to stop.

12. My name will not be used in any part of the study.

13. My data can be used for future research.

14. If I am hurt during the study, Oregon State University has no program to pay for research-related injuries.

15. After talking to the doctor of being hurt from the study, I will call the research team at (541) 737-6919.

16. I will be paid $10.00 for taking part in this research study.

I am taking part because I want to.
I can stop at any time I want to and nothing will happen to me if I do stop.

If I have any questions about this research project, I will contact: Dr. Joonkoo Yun at jk.oregonstate.edu or at (541) 737 – 6919.
If I have questions about my rights or welfare as a participant, I will contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

Do not sign after the expiration date:

Participant's Name (printed): _____

_____ _____
(Signature of Participant) (Date)

_____ _____
(Signature of Person Obtaining Consent) (Date)

College of Public Health and Human Sciences
School of Biological and Population Health Sciences
Kinesiology Program
Oregon State University, 203C Women's building, Corvallis, Oregon 97331
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CONSENT FORM

Project Title:	Validity of Accelerometer for Individuals with and without Down syndrome
Principal Investigator:	Joonkoo Yun
Student Researcher:	Chun (Willie) Leung
Co-Investigator(s):	John Schuna Jr.
Sponsor:	
Version Date:	03/17/2016

1. WHAT IS THE PURPOSE OF THIS FORM?

This form contains information you will need to help you and your son, daughter, or clients to decide whether he or she will be participating in this research study. Please read the form carefully and ask the study team member(s) questions about anything that is not clear.

2. WHY IS THIS RESEARCH STUDY BEING DONE?

As you may well aware of the importance of physical activity in health and the benefits of physical activity had been well documented. The Center of Disease Control (CDC) recommends all Americans to engage in physical activity for at least 150 minutes every week. However, the current research demonstrated significant challenges among individuals with disabilities, (a) many individuals with disabilities do not meet the physical activity recommendation and (b) the accuracy of physical activity measuring tools for individuals with disabilities might not be accurate as they hope. There is a need to further investigate its accuracy. The purpose of this research study is to examine the accuracy of accelerometers (physical activity tracking devices) in measuring physical activity levels among individuals with and without Down syndrome to improve the accuracy of measuring physical activity among individuals with and without Down syndrome. Ultimately, finding a more accurate way to measure physical activity levels using accelerometers. In addition, this study will be used as a partial fulfillment of a degree completion for student researcher, Willie Leung. The results of this study will be use as presentations at a professional meeting and publication in research journal.

Up to 30 participants with Down syndrome may be invited to take part in this study.

3. WHY IS MY SON, DAUGHTER, OR CLIENTS BEING INVITED TO TAKE PART IN THIS STUDY?

Individuals with Down syndrome are being invited to take part in this study because their unique movements characteristics may interfere with the current ways we measure physical activity using accelerometers. We want to find out accurate ways to measure physical activity for individuals with and without DS. Your son/daughter/clients meets the inclusion criteria of over the ages of 18 years diagnosis with Down syndrome and able to walk independently without using any assistive devices for 6 minutes.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

On the day of data collection, we will ask your son/daughter/clients to reframe from eating and engaging in any exercise 3 hours before data collection. Participants will walk for total of 18 minutes on flat surface at 3 different speeds. Participants will walk at a self-selected speed, at 2 mph, and at 4 mph for 6 minutes each. While walking, participants will be wearing an accelerometer on his/her right hip, heart rate monitor over his/her chest, a portable metabolic system over his/her chest with a harness, and a mask over his/her mouth and nose. Between each trial, participants will sit quietly on a chair for 5 minutes. This protocol is designed to measure his/her energy expenditure during walking across at different speeds. The study will last for 60 to 90 minutes long for one to two visits.

Because it is not possible for us to know what studies may be a part of our future work, we ask that you give permission now for us to use personal information and data from the current study without being contacted about each future study. Future use of the participants' information will be limited to studies about physical activity levels, accelerometer accuracies, walking patterns, and energy expenditure of individuals with Down syndrome. If you agree now to future use of the participants' personal information, but decide in the future that participants would like to removed from the research database, please contact Dr. Joonkoo Yun at jk.oregonstate.edu or Willie Leung at leungc@oregonstate.edu. We will be destroying all identifying information after 3 years of completion of the study as required by law. Once the identifying information is destroyed, we will not be able to remove information from the larger dataset.

_____You may store my data from the current study for use in future studies.
Initials

_____ You may not store my data from the current study for use in future studies.
Initials

We may contact you in the future for another similar study. You may ask us to stop contacting you at any time.

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?

No more than minimal risk is expected. It is possible for participants to injure themselves due to falling. To minimize risk of falling and injuries, testing area will be clean with no obstacles and research staff will be close to each participant during testing protocol.

6. WHAT HAPPENS IF I AM INJURED?

Oregon State University has no program to pay for research-related injuries. If you think that your son/daughter/clients have been injured as a result of being in this study, please visit primary health care provider as soon at your convince. After seeking medical treatments or attention, please inform the research team either at 541-737-6919 or at leungc@oregonstate.edu.

7. WHAT ARE THE BENEFITS OF THIS STUDY?
This study is not designed to benefit the participants directly.

8. WILL I BE PAID FOR BEING IN THIS STUDY?
Your son/daughter/client will be paid $10.00 for taking part in this research study. A parking permit will be provided if the testing occurs at Oregon Sate University.

9. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?
Participation in this study is voluntary. If your son/daughter/client decides to participate, he/she is free to withdraw at any time without penalty. He/she will not be treated differently if he/she decides to stop taking part in the study. If he/she chooses to withdraw from this project before it ends, the researchers may keep information collected about he/she and this information may be included in study reports. However, the investigator might terminate participation without informing participants if there were equipment errors, missing data, or participants did not follow instructions for study activities after the completion of the testing protocol.

10. WHO DO I CONTACT IF I HAVE QUESTIONS?
If you have any questions about this research project, please contact: Dr. JoonKoo Yun at jk.oregonstate.edu or at (541) 737 – 6919.

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date:

Participant's Name (printed): _____

_____ _____
(Signature of Participant) (Date)

_____ _____
(Signature of Person Obtaining Consent) (Date)

_____ _____
Parent/Guardian/ Legally Authorized Representative (Date)

College of Public Health and Human Sciences
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CONSENT FORM

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Up to 30 participants without Down syndrome may be invited to take part in this study.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you meet the research criteria of over the ages of 18 years diagnosis without diagnosis of any disability and able to walk independently without using any assistive devices for 6 minutes.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

On the day of data collection, we will ask participants to reframe from eating and engaging in any physical activity 3 hours prior. Participants will walk for total of 18 minutes nn flat surface at 3 different speeds. Participants will walk at a self-selected speed, at 2 mph, and at 4 mph for 6 minutes each. While walking, participants will be wearing an accelerometer on his/her right hip, heart rate monitor over his/her chest, a portable metabolic system over his/her chest with a harness, and a mask over his/her mouth and nose. Between each trial, participants will sit quietly on a chair for 5 minutes. This protocol is designed to measure his/her energy expenditure during walking across at different speeds. The study will last for 60 to 90 minutes long for one visit.

Because it is not possible for us to know what studies may be a part of our future work, we ask that you give permission now for us to use your personal information and data from the current study without being contacted about each future study. Future use of your information will be limited to studies about physical activity levels, accelerometer accuracies, walking patterns, and energy expenditure of individuals with Down syndrome. If you agree now to future use of your personal information, but decide in the future that you would like to have your personal information removed from the research database, please contact Dr. Joonkoo Yun at jk.oregonstate.edu or Willie Leung at leungc@oregonstate.edu. We will be destroying all identifying information after 3 years of completion of the study as required by law. Once the identifying information is destroyed, we will not be able to remove your information from the larger dataset.

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6. WHAT HAPPENS IF I AM INJURED?

Oregon State University has no program to pay for research-related injuries. If you think that you have been injured as a result of being in this study, please visit your primary health care provider as soon at your convince. After seeking medical treatments or attention, please inform the research team either at 541-737-6919 or at leungc@oregonstate.edu.

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This study is not designed to benefit you directly.

8. WILL I BE PAID FOR BEING IN THIS STUDY?

You will be paid $10.00 for taking part in this research study. A parking permit will be provided if the testing occurs at Oregon Sate University.

9. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports. However, the investigator might terminate participation without informing participants if there were equipment errors, missing data, or participants did not follow instructions for study activities after the completion of the testing protocol.

10. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact: Dr. Joonkoo Yun at jk.oregonstate.edu or at (541) 737 – 6919.

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date:

Participant's Name (printed): _____

_____ _____

(Signature of Participant) (Date)

_____ _____

(Signature of Person Obtaining Consent) (Date)

Appendix E: Statistical Analysis Command

Section A: Reading and Managing Data

```
library(plyr)

####Read-in Metabolic Data###
##Read in all files from a directory into a single list of dataframes
files <-
 list.files("H:/Willie_Leung_Data/Oxycon_Data/Clean/",pattern="*.csv",full.names=TRUE
 )
allData <- lapply(files, function(.file){
  dat <- read.csv(.file,header=T,skip=0,na.strings="-")
  id <- rep(substr(.file,46,50),nrow(dat))
  data.frame(id,dat)})

#Combine into single file
met <- do.call("rbind",allData)

##Convert time variable###
met$Time <- as.POSIXct(met$Time, format="%M:%S", origin="1970-01-01")

###Read-in Data Collection Times###
timedat <- read.csv("H:/Willie_Leung_Data/time_data.csv")
        id <- timedat$ID
timedat <- data.frame(id,timedat)

###Convert time variables###
timedat$reststactual <-
 as.POSIXct(paste(timedat$Date.of.Testing,timedat$reststactual),
                        format="%m/%d/%Y %H:%M:%S")
timedat$reststoactual <-
 as.POSIXct(paste(timedat$Date.of.Testing,timedat$reststoactual),
                        format="%m/%d/%Y %H:%M:%S")
timedat$reststaoxy <- as.POSIXct(timedat$reststaoxy, format="%M:%S", origin="1970-
 01-01")
timedat$reststooxy <- as.POSIXct(timedat$reststooxy, format="%M:%S", origin="1970-
 01-01")
timedat$selfstactual <- as.POSIXct(paste(timedat$Date.of.Testing,timedat$selfstactual),
                        format="%m/%d/%Y %H:%M:%S")
timedat$selfstoactual <-
 as.POSIXct(paste(timedat$Date.of.Testing,timedat$selfstoactual),
                        format="%m/%d/%Y %H:%M:%S")
```

```
timedat$selfstaoxy <- as.POSIXct(timedat$selfstaoxy, format="%M:%S", origin="1970-
 01-01")
timedat$selfstooxy <- as.POSIXct(timedat$selfstooxy, format="%M:%S", origin="1970-
 01-01")
timedat$slowstactual <-
 as.POSIXct(paste(timedat$Date.of.Testing,timedat$slowstactual),
                        format="%m/%d/%Y %H:%M:%S")
timedat$slowstoactual <-
 as.POSIXct(paste(timedat$Date.of.Testing,timedat$slowstoactual),
                        format="%m/%d/%Y %H:%M:%S")
timedat$slowstaoxy <- as.POSIXct(timedat$slowstaoxy, format="%M:%S", origin="1970-
 01-01")
timedat$slowstooxy <- as.POSIXct(timedat$slowstooxy, format="%M:%S", origin="1970-
 01-01")
timedat$faststactual <- as.POSIXct(paste(timedat$Date.of.Testing,timedat$faststactual),
                        format="%m/%d/%Y %H:%M:%S")
timedat$faststoactual <-
 as.POSIXct(paste(timedat$Date.of.Testing,timedat$faststoactual),
                        format="%m/%d/%Y %H:%M:%S")
timedat$faststaoxy <- as.POSIXct(timedat$faststaoxy, format="%M:%S", origin="1970-
 01-01")
timedat$faststooxy <- as.POSIXct(timedat$faststooxy, format="%M:%S", origin="1970-
 01-01")

###Merge the two data streams together###
mettime <- merge(met, timedat, by="id", all.x=T)
    ###indicator for mettime with short self-paced stage###
    mettime$shortself <- ifelse((mettime$selfstooxy-mettime$selfstaoxy) <=5, 1, 0)

mettime$rest <- ifelse((mettime$Time >= (mettime$reststaoxy+465)) & (mettime$Time
 <= (mettime$reststooxy-15)),1,0)
mettime$self <- ifelse((mettime$Time >= (mettime$selfstaoxy+225)) & (mettime$Time
 <= (mettime$selfstooxy-15)),1,0)
mettime$slow <- ifelse((mettime$Time >= (mettime$slowstaoxy+225)) &
 (mettime$Time <= (mettime$slowstooxy-15)),1,0)
mettime$fast <- ifelse((mettime$Time >= (mettime$faststaoxy+225)) & (mettime$Time
 <= (mettime$faststooxy-15)),1,0)
mettime$stage <- ifelse(mettime$rest==1, "rest",
                  ifelse(mettime$self==1, "self",
              ifelse(mettime$slow==1, "slow",
                  ifelse(mettime$fast==1, "fast", "ancillary_data"))))

###Process to Participant Level Metabolic Data for Each Stage###
```

```
metfunc <- function(mettime){
            x <- mettime
            id <- x$id[1]; stage <- x$stage[1]
            HR <- mean(x$HR, na.rm=T); BF <- mean(x$BF, na.rm=T); VE <- mean(x$V.E,
 na.rm=T)
            VO2 <- mean(x$V.O2, na.rm=T); VO2kg <- mean(x$VO2.kg, na.rm=T); VCO2 <-
 mean(x$V.CO2, na.rm=T)
            RER <- mean(x$RER, na.rm=T); EE <- mean(x$EE, na.rm=T)
         data.frame(id, stage, HR, BF, VE, VO2, VO2kg, VCO2, RER, EE)}

metdatper <- ddply(mettime, .(id, stage), metfunc, .progress="win")
metdatper <- subset(metdatper, stage!="ancillary_data")

metdatper <- ddply(metdatper, .(id), function(metdatper){
            x <- metdatper
                x1 <- subset(x, stage=="rest")
                indfactor <- x1$VO2kg
            x$MET.normal <- x$VO2kg/3.5
            x$MET.indiv <- x$VO2kg/indfactor
           data.frame(x)}, .progress="win")

###Process to Sample Level###
metdat <- ddply(metdatper, .(stage), function(metdatper){
          x <- metdatper
          HR <- mean(x$HR); BF <- mean(x$BF); VE <- mean(x$VE); VO2 <- mean(x$VO2)
          VO2kg <- mean(x$VO2kg); VCO2 <- mean(x$VCO2); RER <- mean(x$RER); EE <-
 mean(x$EE)
          MET.normal <- mean(x$MET.normal); MET.indiv <- mean(x$MET.indiv)
       data.frame(HR, BF, VE, VO2, VO2kg, VCO2, RER, EE, MET.normal, MET.indiv)},
 .progress="win")
```

Section B: Data Reduction

```
###Read-in and Combine Accelerometer Data###
##Read in all files from a directory into a single list of dataframes
files <-
 list.files("H:/Willie_Leung_Data/Accelerometry_Data/LFE1SEC/CSV/",pattern="*.csv",fu
 ll.names=TRUE)
allData <- lapply(files, function(.file){
  dat <- read.csv(.file,header=T,skip=10)
  id <- rep(substr(.file,53,57),nrow(dat))
  data.frame(id,dat)})
```

```
#Combine into single file
acc <- do.call("rbind",allData)
acc$Time2 <- as.POSIXct(paste(acc$Date,acc$Time), format="%m/%d/%Y %H:%M:%S")

###Merge the two data streams together###
acctime <- merge(acc, timedat, by="id", all.x=T)

acctime$rest <- ifelse((acctime$Time2 >= acctime$reststactual+225) & (acctime$Time2
 < acctime$reststactual+345),1,0)
acctime$self <- ifelse((acctime$Time2 >= acctime$selfstactual+225) & (acctime$Time2 <
 acctime$selfstactual+345),1,0)
acctime$slow <- ifelse((acctime$Time2 >= acctime$slowstactual+225) & (acctime$Time2
 < acctime$slowstactual+345),1,0)
acctime$fast <- ifelse((acctime$Time2 >= acctime$faststactual+225) & (acctime$Time2 <
 acctime$faststactual+345),1,0)
acctime$stage <- ifelse(acctime$rest==1, "rest",
                  ifelse(acctime$self==1, "self",
              ifelse(acctime$slow==1,"slow",
                  ifelse(acctime$fast==1, "fast", "ancillary_data"))))

###Process to Participant Level Accelerometer Data for Each Stage###
accfunc <- function(acctime){
          x <- acctime
          id <- acctime$ID[1]
          Axis11 <- sum(head(x$Axis1,60)); Axis21 <- sum(head(x$Axis2,60)); Axis31 <-
 sum(head(x$Axis3,60))
          Axis12 <- sum(tail(x$Axis1,60)); Axis22 <- sum(tail(x$Axis2,60)); Axis32 <-
 sum(tail(x$Axis3,60))
          VM1 <- sqrt(Axis11^2+Axis21^2+Axis31^2); VM2 <-
 sqrt(Axis12^2+Axis22^2+Axis32^2)
          Steps1 <- sum(head(x$Steps,60)); Steps2 <- sum(tail(x$Steps,60))
          ###Compute Average for Two Minutes###
          Axis1 <- mean(c(Axis11,Axis12)); Axis2 <- mean(c(Axis21,Axis22)); Axis3 <-
 mean(c(Axis31,Axis32))
          VM <- mean(c(VM1,VM2)); Steps <- mean(c(Steps1,Steps2))
        data.frame(id, Axis1, Axis2, Axis3, VM, Steps)}

accdatper <- ddply(acctime, .(id, stage), accfunc, .progress="win")
accdatper <- subset(accdatper, stage!="ancillary_data")

###Process to the Sample Level###
accdat <- ddply(accdatper, .(stage), function(accdatper){
                          x <- accdatper
```

```
                    stage <- x$stage[1]
                    Axis1 <- mean(x$Axis1); Axis2 <- mean(x$Axis2); Axis3 <-
 mean(x$Axis3);
                    VM <- mean(x$VM); Steps <- mean(x$Steps)
                data.frame(stage,Axis1,Axis2,Axis3,VM,Steps)}, .progress="win")

###Merge the accelerometer and the metabolic data###
dat <- merge(accdatper, metdatper, by=c("id","stage"))

write.table(metdatper,"H:/Willie_Leung_Data/Processed_Datasets/metabolic_data_per
 _person.csv",sep=",",
        na="",col.names=T,row.names=F,quote=F,append=F)
write.table(metdat,"H:/Willie_Leung_Data/Processed_Datasets/metabolic_data_sample
 .csv",sep=",",
        na="",col.names=T,row.names=F,quote=F,append=F)
write.table(accdatper,"H:/Willie_Leung_Data/Processed_Datasets/accelerometer_data_
 per_person.csv",sep=",",
        na="",col.names=T,row.names=F,quote=F,append=F)
write.table(accdat,"H:/Willie_Leung_Data/Processed_Datasets/accelerometer_data_sa
 mple.csv",sep=",",
        na="",col.names=T,row.names=F,quote=F,append=F)
write.table(dat,"H:/Willie_Leung_Data/Processed_Datasets/combined_metabolic_accel
 erometer_data_per_person.csv",sep=",",
        na="",col.names=T,row.names=F,quote=F,append=F)
```

Section C: Correlation Coefficients (Mixed Design)

```
library(plyr)
library(nlme)
library(lme4)
library(cocor)

##########Repeated Measures Correlation Function############################
repcor <- function(x, y, id){

 if (length(x) != length(y) | length(x) != length(id)){
  return("input data not in the proper format")}
 else {

  value <- c(x,y)
  repl <- ave(x, id, FUN = seq_along)
  variable <- c(rep("x",length(x)),rep("y",length(x)))
```

```
  id <- rep(id,2)
  Replicate <- rep(repl, 2)
  value1 <- value - mean(value)

  a <- data.frame(id, Replicate, variable, value1)

  one <- lmer(value1 ~ variable + (1+variable|id) + (1+variable|id:Replicate), data=a,
REML=F,
          control=lmerControl(check.nobs.vs.nlev = "ignore",check.nobs.vs.rankZ =
                        "ignore",check.nlev.gtreq.5 = "ignore",check.nobs.vs.nRE="ignore",
                      check.rankX =    c("ignore"),
                      check.scaleX = "ignore",
                      check.formula.LHS="ignore",
                      check.conv.grad   = .makeCC("warning", tol = 1e-3, relTol = NULL),
                      optCtrl=list(maxfun=20000)))

  ####Get Variance Components####
  vc <- VarCorr(one); varcomps <- c(unlist(lapply(vc, diag)), attr(vc,"sc")^2)
  resvar <- tail(varcomps,1)

  ###Get Variance Matrices
  ###id matrix###
  idvar <- vc[2]
  ###Get SAS Equivalent Variance Partitions###
  un11id <- as.numeric(idvar$id[1,1]);un12id <- as.numeric(un11id + idvar$id[2,1])
  un13id <- as.numeric(un11id + idvar$id[2,1] + idvar$id[1,2] + idvar$id[2,2])
  ##id:repl matrix###
  idreplvar <- vc[1]
  ###Get SAS Equivalent Variance Partitions###
  un11idrepl <- as.numeric(idreplvar$id[1,1] + resvar);un12idrepl <-
as.numeric(idreplvar$id[1,1] + idreplvar$id[2,1])
  un13idrepl <- as.numeric(un11idrepl + idreplvar$id[2,1] +
                    idreplvar$id[1,2] + idreplvar$id[2,2])
  ###Construct Diagonal Matrix Equivalent to that in SAS V Matrix###
  vmat <- matrix(c(un11id+un11idrepl, un12id+un12idrepl,un12id+un12idrepl,
un13id+un13idrepl), ncol=2)
  ###Convert to Correlation Matrix###
  vcor <- cov2cor(vmat)
  corval <- vcor[1,2]
  return(corval)}}
```

Section D: Within Group Comparison (Meng's z – test)

```
####Correlations and P-values from Within Group Tests###
cordat <- rbind(totsamp,groupsamps)

###Correlations p-values from between group Comparisons###

Axis1bg <- cocor.indep.groups(cordat$Axis1_VO2kg[2],cordat$Axis1_VO2kg[3],
                    sum(dat1$Group==0),sum(dat1$Group==1))@fisher1925$p.value
Axis2bg <- cocor.indep.groups(cordat$Axis2_VO2kg[2],cordat$Axis2_VO2kg[3],
                    sum(dat1$Group==0),sum(dat1$Group==1))@fisher1925$p.value
Axis3bg <- cocor.indep.groups(cordat$Axis3_VO2kg[2],cordat$Axis3_VO2kg[3],
                    sum(dat1$Group==0),sum(dat1$Group==1))@fisher1925$p.value
VMbg <- cocor.indep.groups(cordat$VM_VO2kg[2],cordat$VM_VO2kg[3],
                  sum(dat1$Group==0),sum(dat1$Group==1))@fisher1925$p.value

cordat2 <- data.frame(Axis1 = Axis1bg, Axis2 = Axis2bg, Axis3 = Axis3bg, VM = VMbg)

Axis1bg <- cocor.indep.groups(cordat$Axis1_VO2kg[2],cordat$Axis1_VO2kg[3],
                    sum(dat1$Group==0),sum(dat1$Group==1))@zou2007
Axis2bg <- cocor.indep.groups(cordat$Axis2_VO2kg[2],cordat$Axis2_VO2kg[3],
                    sum(dat1$Group==0),sum(dat1$Group==1))@zou2007
Axis3bg <- cocor.indep.groups(cordat$Axis3_VO2kg[2],cordat$Axis3_VO2kg[3],
                    sum(dat1$Group==0),sum(dat1$Group==1))@zou2007
VMbg <- cocor.indep.groups(cordat$VM_VO2kg[2],cordat$VM_VO2kg[3],
                  sum(dat1$Group==0),sum(dat1$Group==1))@zou2007
LL <- c(Axis1bg$conf.int[1],Axis2bg$conf.int[1],Axis3bg$conf.int[1],VMbg$conf.int[1])
UL <- c(Axis1bg$conf.int[2],Axis2bg$conf.int[2],Axis3bg$conf.int[2],VMbg$conf.int[2])

cordat22 <- data.frame(Axis = c("Axis1","Axis2","Axis3","VM"),LL,UL)

####Correleations and P-values from Within Group Tests###
cordatb <- rbind(totsamp,groupsamps)
```

Section E: Between Group Comparison (z – test)

```
###Correlations p-values from between group Comparisons###

Axis1bg <- cocor.indep.groups(cordatb$Axis1_VO2kg[2],cordatb$Axis1_VO2kg[3],
                    sum(dat$Group==0),sum(dat$Group==1))@fisher1925$p.value
Axis2bg <- cocor.indep.groups(cordatb$Axis2_VO2kg[2],cordatb$Axis2_VO2kg[3],
                    sum(dat$Group==0),sum(dat$Group==1))@fisher1925$p.value
```

```
Axis3bg <- cocor.indep.groups(cordatb$Axis3_VO2kg[2],cordatb$Axis3_VO2kg[3],
                    sum(dat$Group==0),sum(dat$Group==1))@fisher1925$p.value
VMbg <- cocor.indep.groups(cordatb$VM_VO2kg[2],cordatb$VM_VO2kg[3],
                  sum(dat$Group==0),sum(dat$Group==1))@fisher1925$p.value

cordat2b <- data.frame(Axis1 = Axis1bg, Axis2 = Axis2bg, Axis3 = Axis3bg, VM = VMbg)

Axis1bg <- cocor.indep.groups(cordatb$Axis1_VO2kg[2],cordatb$Axis1_VO2kg[3],
                    sum(dat$Group==0),sum(dat$Group==1))@zou2007
Axis2bg <- cocor.indep.groups(cordatb$Axis2_VO2kg[2],cordatb$Axis2_VO2kg[3],
                    sum(dat$Group==0),sum(dat$Group==1))@zou2007
Axis3bg <- cocor.indep.groups(cordatb$Axis3_VO2kg[2],cordatb$Axis3_VO2kg[3],
                    sum(dat$Group==0),sum(dat$Group==1))@zou2007
VMbg <- cocor.indep.groups(cordatb$VM_VO2kg[2],cordatb$VM_VO2kg[3],
                  sum(dat$Group==0),sum(dat$Group==1))@zou2007
LL <- c(Axis1bg$conf.int[1],Axis2bg$conf.int[1],Axis3bg$conf.int[1],VMbg$conf.int[1])
UL <- c(Axis1bg$conf.int[2],Axis2bg$conf.int[2],Axis3bg$conf.int[2],VMbg$conf.int[2])

cordat22b <- data.frame(Axis = c("Axis1","Axis2","Axis3","VM"),LL,UL)
```