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Comparative Kinematic Gait Analysis in Adults with Multiple Disabilities

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COMPARATIVE KINEMATIC GAIT ANALYSIS IN ADULTS WITH MULTIPLE DISABILITIES

by

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Abstract

The purpose of this research is to identify abnormal gait parameters or patterns amongst young adults with multiple disabilities enrolled in a work transition program sponsored by a public-school system. Gait disorders are commonly seen in individuals with neurologic disorders, with significant research in children with autism. Gait disorders have been linked with fall and injury risk, with significant research in elderly populations. Gait analysis technology can be used to identify gait characteristics in populations that are abnormal or contribute to gait disorders. In an observational design, students from the transitional program promoted by Westerville City Schools, housed on Otterbein University campus were the focus population. These students are classified as young adults, aged 18-22 years old, with multiple disabilities. These participants were then gender-matched with healthy Otterbein Student volunteers 18-22 years old. Each participant underwent an hour-long observational session in the Biomechanics Institute at Otterbein university. Gait parameter and kinematic data was collected for each subject. Descriptive statistics and a Mann-Whitney U test was run for statistical significance of values. Significant differences between groups were found for left and right limb walking speeds, right limb step length, right limb step time, left and right limb opposite foot off, right double support, left knee maximum flexion, left knee minimum flexion, and left knee valgus. The gait parameter differences observed were consistent with an overall decreased walking speed and decreased step length in the Best of Both Worlds members, which can contribute to injury risk and decreased community ambulation. Values contributing to decreased walking speeds in the subjects of the BoBW population require further research to identify specific causes, but overall gait differences were identified. Abnormal gait parameter and kinematic information can be an indicator of injury and fall risk and can serve as a clear descriptor of mobility.

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Introduction

Purpose

The purpose of this research is to identify abnormal gait parameters or patterns amongst youth with multiple disabilities enrolled in a work transition program sponsored by a public-school system. Previous literature has established that children who have been diagnosed with autism spectrum disorder (ASD) have certain gait characteristics that are abnormal. However, most of the established literature examining gait characteristics has been conducted on children (less than 18 years old) with ASD. There is, therefore, a gap in the literature on gait patterns in the 18-22-year-old age group of individuals with multiple disabilities that may include but are not exclusive to ASD. Many of these young adults are enrolled in work transition programs to facilitate their entry into the workforce. Although there is a great attention to work and life skills given to adults enrolled in these programs to better equip these individuals for healthy engagement in society, it is important to consider health-related barriers that adults with disabilities might face as they leave school-based interventions that might have included adapted physical education, physical therapy and occupational therapy services.

Implications

The goal of the study is to compile kinematic data on a population where there is little available data regarding gait characteristics. The kinematic data will be compared to an age-matched control group of adults without identified disabilities. The results of this research could provide insight into important limitations or impairments in the gait cycle that could place the individuals at risk for falls or cause a lack of participation in typical health and fitness activities for young adults.

Assumptions

Assumptions made throughout the study are that the participants' diagnosed disability as the primary contributor to any abnormal gait characteristics. Similarly, it was assumed that no other physical injuries were contributing to the participants' gait characteristics.

Literature Review

Background

With the passing of the Individuals with Disabilities Education Act (IDEA) in 1997, there became more accountability and representation for transitional programs in the United States. The objective of this act was to assist in youth transitions from grade school into practical options post-education such as employment. This act focused on a diverse population that had many variations within its members. An article written in 2002, which aimed to identify the characteristics and flaws within transitional programs in the United States, defined this select group as youth with “a limitation in functioning that stems from the presence of a physical or mental impairment” (Wittenburg, Golden, & Fishman, 2002, p. 196). The individuals who are intended to benefit from these transitional programs vary in characteristics and come to the programs with a broad range of experiences, needs, and different environmental factors that contribute to the kinds of accommodations they require (Wittenburg et al., 2002). Under the IDEA, a state is required to evaluate all children with disabilities that need special education services (Wittenburg et al., 2002). Wittenburg identified two main categories of these transition programs (2002). One category includes school-based programs which require the development of an Individualized Education Plan, or IEP. The IEP allows for specialized services and are developed for a specific student's needs (Wittenburg et al., 2002). Wittenburg identified one fault of these programs being higher levels of variation across states and programs as the population and needs are so diverse. This means that different government agencies control different services. The involvement of multiple government agencies causes inconsistent or conflicting aspects within programs such as requirements and outcomes (Wittenburg et al., 2002). Another disadvantage to these programs is that they occur while a child is in school. As young adults complete formalized schooling they often find less support in post-school programs, and some young adults lose access to any programming at all (Wittenburg et al., 2002). The second category that Wittenburg identified includes non-school programs that are specific to certain selective population portions with services such as health insurance, cash assistance, rehabilitation and employment support programs, and more (2002). Vocational Rehabilitation (VR) falls within this category. Vocational Rehabilitation programs are typically, "a nationwide federal-state program that provides medical, therapeutic, counseling, education, training, work-related placement assistance, and other services needed to prepare people with disabilities for work" (Wittenburg et al., 2002, p. 199). These programs aim to create employment and job transition options and opportunities for this population (Wittenburg et al., 2002). As stated previously, there is less support and access for these services under the IDEA than the school-based programs, so an even smaller selection of the population can benefit from these services (Wittenburg et al., 2002). Wittenburg identified the importance of these programs in that many students struggle with losing the consistent structure and support that school supplies (2002) in their post-school transition. Wittenburg developed a flowchart in which he identified the two main paths a young adult with disabilities can take in their post-school transition (2002). One path is into post-school support, such as transfer programs, and the other path is into post-school activities, such as employment and work (Wittenburg et al., 2002). While there are these two identified paths, often each individual's path is not clear cut as certain funding and needs are unique to each.

Transition programs are essential in aiding young adults with multiple disabilities in their transition from pediatric health care into adult health care and into the work force post-school. In an article written about Kentucky's transition program initiative, “Healthy and Ready to Work,” Blomquist states, “Young people with special healthcare needs experience fewer opportunities for employment and independent living because of difficulty with mobility, transportation, finances, maintaining health and functional abilities, and low expectations from people around them (Blomquist, 2008, p. 515). This population must overcome many barriers to find success in and after this transition, and these programs aim to do just that. Kentucky’s “Healthy and Ready to Work Initiative” is funded through the state’s Federal Health Resources and Services Administration (HRSA)/Maternal and Child Health Bureau (Blomquist, 2008). The goal of this initiative is to develop programs that fit this population’s needs in health care, health promotion, skills development, and more to ensure their success (Blomquist, 2008).

It has been identified that this population has been found to have struggles succeeding and maintaining stability within the post-school activities path in employment and researchers have aimed to identify possible barriers to success (Ratzon, Schejter, Alon, & Schreuer, 2010). These researchers attempted to identify physical work demands for youth with disabilities (Ratzon et al., 2010). A select population described as ‘youth and adolescents with special needs’ (YASN) were recruited from local transitional programs and were evaluated using multiple physical and rehabilitation tools to identify this population’s physical abilities and attempted to determine if physical demands resulted in their struggles to maintain employment post-school (Ratzon et al., 2010). Prior to the study, it was identified that a low percent of the YASN population maintained their jobs post-school, and that the majority entered blue-collared, labor jobs (Ratzon et al., 2010). This led researchers to question if the low rates of maintaining employment were a result of the physical demands of these jobs. To assess the physical capacity of this population, Ratzon et al evaluated 26 young adults with an average age of 20 years old (2010). Within the study, there were 13 individuals within the YASN population, and 13 individuals without classified disabilities who graduated and studied in mainstream schools (Ratzon et al., 2010). Of the 13 individuals in the YASN group, diagnoses ranged from attention deficit hyperactivity disorder, learning disorder, pervasive developmental disorder, communication disorders, and developmental coordination disorder (Ratzon et al., 2010). Researchers used the Functional Capacity Evaluation (FCE), a performance test used to identify the performance of daily living activities compared to individual physical capacity, in addition to two sections within the Physical Work Performance Evaluation (PWPE): Dynamic Strength, and Fine motor function and Hand dexterity (Ratzon et al., 2010). Together these functional capacity evaluations were used to assess each subject as they related to work requirements. To test for dynamic strength, subjects performed varied box lifting activities under specific requirements (Ratzon et al., 2010). To test for fine motor function and hand dexterity, subjects performed pinboard exercises specific to industrial worker screening processes, as well as a 12-fastener exercise to evaluate hand dexterity (Ratzon et al., 2010). These tests were administered by trained and licensed Occupational Therapists. Upon completion of these evaluations, a significant difference between the physical capacity of the two separate groups was identified (Ratzon et al., 2010). The most notable difference was among the subsets of the PWPE that employed timed performance. There were recognized differences between the two groups scores within the dynamic strength tests, and an increased average grip strength within the control group verses YASN (Ratzon et al., 2010). With the identified differences in physical capacity within this selected population (YASN), the application of these differences to the physical requirements within labor intensive jobs could contribute to successful completion of job-related tasks within this population as compared to those without identified disabilities. While a clear connection between decreased physical capacity and post-school success within transitional programs for youths with disabilities requires more research, it has been found that promoting physical activity within this population can have positive benefits in physical heath (Rimmer & Rowland, 2008).

An article written in 2008 by Rimmer and Rowland discussed the benefits of increasing physical health amongst children and adolescents with disabilities. It has been identified that the rate of inactivity among adolescents with disabilities is higher than similarly aged adolescents without disabilities (Rimmer & Rowland, 2008). Regular physical activity can improve health through increasing bone density, improving body weight management, decreasing risk of high blood pressure, and decreasing feelings of depression (Rimmer & Rowland, 2008). All the benefits from increased physical activity are reasons to promote physical activity at all ages, for all adolescents. Rimmer and Rowland identified a decreased rate in physical activity can contribute to an increase in obesity rates in adolescents with disabilities. However, exercise programs for this population have been shown to increase strength and cardiovascular endurance in individuals (2008). Rimmer and Rowland proposed development of "PEP for Youth Program", or a personalized exercise program that is internet based and intended to increase adolescents with disabilities' physical activity rate (2008). This program utilized information technology (IT) to combine clinical outcome measurements and personalized wellness assessments to create an individual plan for adolescents with disabilities (Rimmer and Rowland, 2008). The program involved problem identification with a "needs assessment", then a personalized physical and nutritional program combined with accessing school and community resources, to contribute to long term support (Rimmer and Rowland, 2008). Promoting physical activity within these programs can have generalized positive effects, however, these types of personalized plans are not easily accessible to all adolescents with disabilities and require high amounts of support from either a therapist or healthcare provider and family and community support. Access to these resources is not universal for all members of such a large and diverse population (Rimmer and Rowland, 2008). As noted in Ratzon et al. (2010), researchers identified specific differences in motor area functions that can contribute to reduced employment success such as decreased timed performance and grip strength in young adults with multiple disabilities as compared to age-matched individuals outside of this population. Considering these differences and their application to labor demands and prediction of potential injury or risk, there are other generalized predictors of injury risk for many different populations, one of which being gait.

Allied Research

Gait is defined as "a cyclic pattern of body movements which advances an individual's position" (Ueda et al., 2017, p. 37). The gait cycle is divided up into identifiable sections or moments. The two main phases of a complete gait cycle are stance and swing (Nandy et al., 2021). Stance phase is considered weight-bearing for an identified lower extremity, and swing phase is considered non-weightbearing (Nandy et al., 2021) for the identified lower extremity. Stance phase is further divided into subphases: heel strike, foot-flat, midstance, heel-off, and toe off (Nandy et al., 2021). Swing phase is further divided into subphases: acceleration, midswing, and deceleration (Nandy et al., 2021). All of these subphases describe the position of the lower limb in relation to the ground (Nandy et al., 2021). Stance phase contributes to about 60% of a full gait cycle, whereas swing phase contributes to about 40% of the total gait cycle (Hazari et al., 2021). The swing phase contributes to the momentum that propels the body forward in gait and allows for walking to be a low energy expenditure activity (Hazari et al., 2021). Different gait parameters can be further identified using these subphases and provide researchers and clinicians with information about an individual's walking speed, cadence, stance width, step length, stride length, stride time, step time (Hazari et al., 2021). With the utilization of these subphases, gait analysis can be applied to identify abnormalities within a clinical setting. Many of these characteristics can then aid in the identification of fall or injury risk patterns (Hausdorff, 2005).

Abnormalities within different gait parameters are utilized in gait analysis studies for clinical applications (Chambers & Sutherland, 2002). In a guide to gait analysis, clinicians provide a summary as to how gait parameters can help identify certain risk factors . Chambers and Sutherland describe "measurements of kinematics, kinetics, muscular activity, foot pressure, and energetics done in the motion analysis laboratory" as the tools that can be used in gait analysis (Chambers & Sutherland, 2002, p. 230). Chambers and Sutherland describe the advancements within gait analysis and provide summaries with supporting research detailing how each variable can be linked to clinical improvement (2014).

When considering what is essential when focusing on motor development and injury risk indicators for many populations, gait analysis can provide key information on fall predictors and motor delays. Gait is a lifelong motor skill and typically develops within the first few years of life and into childhood and adulthood (Jequier et al., 2021). Research has shown that gait parameters can be indicators of mobility and fall risk (Hausdorff, 2005).

In a prospective cohort study performed in Boston in 2001, 52 subjects with an average age of 80 years old underwent initial testing, then a follow-up 12 months later (Hausdorff et al). During this 12-month period, any subject falls were reported and compared to their baseline gait testing prior to the 12 months (Hausdorff et al., 2001). The initial testing also involved collection of demographic data, health status, mental status, self-rated quality of life (QOL), functional status, muscle strength, balance, and gait characteristics (Hausdorff et al., 2001). Gait and balance tests were completed using the Functional Reach Test, one-legged stance time (eyes open and closed), tandem stance time, the Timed Up and Go, and the Performance-Oriented Mobility Scale (Hausdorff et al., 2001). Force measuring insoles were used to measure gait variability with measurements such as stride and swing periods during controlled walking trials (Hausdorff et al., 2001). After 12 months, when comparing the subjects that had suffered a fall within the time period to those that had not suffered a fall, the subjects who experienced a fall displayed a significant amount of increased gait variability, particularly stride-time variability, than those that did not report a fall (Hausdorff et al., 2001). This study was able to identify a connection between gait variability and future fall risk predictors, contributing to the argument that gait is a relevant parameter in the evaluation of fall risk and mobility in elderly or at-risk populations. Gait variability, specifically decreased step length, can contribute to abnormal gait patterns, described as "shuffling gait", often seen in Parkinson's patients (Zhang et al., 2021). This gait characteristic is linked with clear indication for injury and fall risk (Yamashita et al., 2011). Through gait analysis on Parkinson's patients, identifying gait abnormalities can be useful in injury prevention techniques.

Three-dimensional gait analysis is a form of gait analysis that can provide specific information on gait parameters across a wide range of populations. The benefit of three-dimensional gait analysis is that it can capture over-ground gait without requiring the use of treadmill walking and it is minimally invasive testing. Most motion capture technology that is used to assess gait uses reflective markers placed on various parts of the lower body surrounding key joints such as the hip, knee, and ankle. These markers create an embedded coordinate system that forms a 4-segment rigid body model that is then used to analyze joint kinematics.

In 1990, Kadaba et al. identified gait parameters using VICON motion capture technology (Kadaba, Ramakrishnan, & Wootten). Over the course of three weeks, researchers assessed 40 normal healthy subjects between the ages of 18-40 years old in three different walking trials in a motion capture lab using VICON cameras (Kadaba et al., 1990). The walking trials were spread out over the three weeks to test reliability of the technology when comparing each subject's data against their own (Kadaba et al., 1990). This study was a major building block for future motion capture and gait research studies that have come after it. VICON, a significant motion capture technology company, has since created a pipeline to create the 4-segment rigid body within its software NEXUS 2.0 called “Plug-in-Gait". This pipeline acts as a “short cut” to the work that Kadaba et al. performed. “Plug-in-gait generates virtual marker trajectories that represent kinematic and kinetic quantities and representations of the modeled segments” (NEXUS User guide, 2016, p.172). This pipeline allows the rigid body to be created automatically without having to manually apply the embedded coordinate system and model. For non-complex movements such as walking, this pipeline allows for easy exportation and analysis of kinematic gait data. This technology has been employed in studies examining different populations other than elderly and has been validated within the literature as an acceptable tool for gait analysis and identification of gait abnormalities.

A literature review completed in 2015 compiled different studies that examined gait analysis in individuals with intellectual disabilities (Almuhtaseb, Oppewal, & Hilgenkamp). The studies used different analysis techniques on different populations. The reviewers compiled information gathered in over-ground walking studies which used spatio-temporal gait parameters, kinematic gait parameters, kinetic gait parameters, and dynamic EMG gait parameters (Almuhtaseb et al., 2015). Applied to different populations with intellectual disabilities, the review compared the findings between studies and attributed certain findings as possible contributors to gait abnormalities such as physical appearance and cognitive effects. These studies utilized gait analysis to identify abnormalities in a particular population of interest.

Critical Research

It has been established that gait parameters can be used as predictors to fall risk and used in evaluating mobility (Almuhtaseb et al., 2015, Hausdorff et al., 2001). Many studies have used motion capture technology to identify gait abnormalities in children with autism (Calhoun, Longworth, & Chester, 2010; Eggleston, Harry, Hickman, & Dufek, 2017). A study conducted in 2010 at the University of New Brunswick used VICON motion capture technology to identify gait patterns in children aged 5-9 years old diagnosed with autism spectrum disorder (Calhoun et al.). Twelve children were selected for the study and exclusions consisted of those diagnosed with Asperger's disorder, a non-specified pervasive developmental disorder, and toe-walkers (Calhoun et al., 2010). Of the 12 children, 33% had confirmed hypotonia, or low muscle tone, and 25% reported gross motor delays during development (Calhoun et al., 2010). Gait parameters collected on the 12 subjects were compared to previously collected controlled data from 22 neuro-typical children aged 5-9 years old in a 2006 study (Calhoun et al., 2010). Gait kinematics were collected using an 8-camera VICON motion capture system and 4 force plates. Twenty reflective markers were placed on each subject's lower body based on a rigid body model previously established (Calhoun et al., 2010). Each subject performed typical walking trials in the motion capture space, and the gait cycle that was most similar to the individual mean was used for further analysis (Calhoun et al., 2010). The researchers used an embedded coordinate system created based on the joint marker placements, and thus were able to establish joint angles changes during the walking trials (Calhoun et al., 2010). A one-way ANOVA analysis was used to identify gait parameter differences in the experimental group versus the control data (Calhoun et al., 2010). Among the significant differences found, the Autism group showed increased cadence, increased peak dorsiflexion angles in swing phase, and increased peak hip flexion angles in stance (Calhoun et al., 2010). In summary, researchers found significant differences in plantarflexion moments and angles, as well as differences in hip flexor moments and angles (Calhoun et al., 2010). They attributed the differences in plantar flexion moments and decreased plantar flexion angles to hypotonia which was identified in 33% of the autism testing group (Calhoun et al., 2010). Additionally, decreased hip extensor moment activity researchers attributed increased peak hip flexion angles, but there is a lack of research to explain the findings (Calhoun et al., 2010). This study identified that there are key differences in the gait patterns of children diagnosed with autism as compared to neurotypical children of a similar age and used motion capture technology to identify joint angles and moments that were identified as different within comparison. Another study performed in 2017 analyzed gait symmetry in a similar population (Eggleston et al.).

Eggleston et al. performed a motion capture study to identify possible lower extremity gait symmetry parameters in children with autism spectrum disorder (2017). Researchers compared the kinematic data of 10 children, aged 5-12 years old, diagnosed with autism (Eggleston et al., 2017). The subject's gait parameters were measured using an 8-camera VICON motion capture lab, with 2 embedded force plates in the ground of the testing space (Eggleston et al., 2017). Nineteen reflective markers were placed on the subjects lower-extremities, and they were instructed to walk at a self-selected velocity through the testing space in multiple trials

(Eggleston et al., 2017). A point-by-point procedure-model technique was used to identify statistically significant differences between left and right lower extremities of the subject's joint positions at different points in their gait cycle (Eggleston et al., 2017). Researchers found statistically significant differences between the left and right joint positions of the hip, knee, and ankle joints throughout the gait cycles of the subjects (Eggleston et al., 2017). Researchers did not find any consistent asymmetry between the subjects, showing that their technique was successful at identifying differences in gait within each subject's own gait cycle, but these differences bilaterally were not consistent across all subjects (Eggleston et al., 2017). This study further demonstrates how this population displays characteristics of gait instability individually.

Literature Summary

Previous studies have utilized the use of motion capture technology to perform minimally invasive analyses on a population of interest. There is an identified gap in the populations that are served through transitional programs in the United States. Transitional programs are used to aid in young adult's transition from pediatric health care and education, and with the percentage of young adults with disabilities who cannot maintain a job being so high, it is important to identify all contributing factors. While young adults diagnosed with autism spectrum disorder are among the population classified under "young adults with multiple disabilities," there is a lack of gait research on young adults with autism, and similarly on this population in general. Research has shown that when compared to controls, young adults with multiple disabilities are found to struggle with dynamic strength tests involving a timed element, as well as displaying decreased grip strength. This motor information is important as it can be addressed within transitional programs, or in the workplace where accommodation can be made. While there are many different diagnoses within this population and there is no way to definitively determine a gait characteristic that is both abnormal and consistent amongst them all, it is clear in the research that gait parameter information can be an indicator of injury and fall risk and serve as a clear descriptor of mobility. In a population where physical demands may increase due to transition into the work force, it is important to identify if gait instability is an overarching issue or if there are any gait abnormalities within this population. There are high levels of success in gait analysis being utilized in injury risk identification and injury prevention in elderly individuals. Data collected within a population of adults with disabilities pertaining to gait parameters in comparison to control populations of similar age may contribute to identification of areas of focus that can be applied to transitional programs to help maximize the future success of this population in and out of the workplace.

Research Questions

1. Among college aged (18-22 years old) individuals with multiple disabilities enrolled in a public school sponsored transitional program housed at Otterbein University, are there identifiable gait characteristics that can be found using motion-capture technology?
2. When compared to other college aged individuals without disabilities, are there identifiable gait characteristics amongst young adults with multiple disabilities?

The goal of the study is to compile kinematic data on a population where there is little available data regarding gait characteristics. The kinematic data will be compared to an age-matched control group of adults without identified disabilities. The results of this research could provide insight into important limitations or impairments in the gait cycle that could place the individuals at risk of falls or lack of participation in typical health and fitness activities for young adults.

Methods

Participants

The study was approved by the Otterbein Institutional Review Board (IRB) (Appendix A). Participants for this study were solicited to volunteer for this study from the Westerville City Schools' work transition program that is housed on Otterbein's campus with a solicitation statement provided to the students in the program and their legal guardians (Appendix B). This program is known as the "Best of Both Worlds" program (BoBW). This program is a transitional-work program that is designed to provide work, community, and life skills experiences to 18–22-year-old public school students with identified disabilities (Appendix C). A total number of four BoBW students volunteered to participate in the study, three females and one male. Control subjects were solicited through emails sent to the general population of Otterbein students to provide comparative data with similarly aged students without identified disabilities and who are not participating in a transitional program. There were four control subjects who were gender-matched with the BoBW subjects. Subjects excluded from the study were those that had any chronic or acute lower extremity injury that altered normal walking gait. No students were forced to take part in any physical tasks or participate in the study. To ensure that no one was forced to participate, all participants were over 18 years of age and were asked to provide oral assent to participate and the participants and their legal guardians (if applicable) were asked to sign the Consent for Participation in Social and Behavioral Research form which acknowledged that they were free to withdraw consent at any time and to discontinue participation in the study without prejudice (Appendix D). Researchers collecting data were trained and experienced in the motion capture technology used in data collection.

Materials

To analyze biomechanics pertaining to gait, 3D motion capture was used. Data was collected in Otterbein University's Biomechanics Institute. This lab contains a 10-camera

VICON system that uses Nexus 2.0 software to collect and process kinematic data. The lab cameras are mounted above the data collection space on a metal frame suspended in the room. The data collection area was a wide-open, level space to mimic typical above ground walking conditions. Within the Nexus software, the “Plug-in-Gait" pipeline that has previously been developed to process gait data was used to model reflective marker placement and data processing. Both groups required the use of reflective diodes and double-sided tape to place markers for kinematic data collection, as well as a desktop computer with the Nexus software to process data to be later analyzed. The use of colored tape on the floors in the lab was used to aid in verbal and visual instruction during kinematic data collection to cue the stop and start lines for gait analysis.

Design

The design of this study was observational. Each subject was individually analyzed on different gait parameters relating to lower limb movements, with a focus on ankle, knee, and hip movements and angles. No interventions were provided, and no longitudinal analysis was conducted. All subject data was combined within both groups, to identify commonalities, as well as differences, relating to which group they belong using descriptive analysis. The goal of the study was to identify any gait characteristics and abnormalities in the BoBW group that may be consistent with previously established abnormal gait parameters in neuro and elderly populations. Descriptive data analysis was applied, along with a Mann-Whitney U test to identify a significant difference between the two groups. The collection of data within an experimental setting and unfamiliar environment was a variable to consider, but this condition remained constant for both groups. Similarly, subject awareness of active motion analysis as they perform tasks could have impacted the production of normal gait frequencies and parameters. Variables that could have affected comparison are the nonspecific or generalized diagnosis within the BoBW group. However, the intent of the study was to identify gait parameter and abnormalities despite the wide range of diagnoses within a transitional group.

Procedure

Prior to the study, pilot data was collected on individuals from Otterbein's Health and Sport Science department students. This pilot data was used to determine design of the data collection sessions such as number of trials needed and chosen cycle of analysis. It was determined that three walking trials for each participant provided sufficient data for analysis, and the 2^{nd} cycle of each trial was representative of the subject's normal gait. Once the subjects were determined, the kinematic data was collected over multiple weeks, with each subject only participating in a single, one-hour session in the motion capture lab. Subjects were assigned a time to be analyzed. As the design of the study was not experimental or dependent on time, the times were made based upon the availability of each subject independently. Participants were given compression shorts to wear that lacked reflective materials as not to interfere with the reflective markers for data collection. Subjects were allowed to bring a guardian or guest to ensure a calm and controlled environment. Prior to marker placement, each subject received an explanation of where the markers were going to be placed and an example of the tape that is used. Researchers worked to ensure minimal distractions and maximal privacy during the data collection. Each BoBW subject had a BoBW job coach in attendance during their session to ensure a stable environmental factor. If at any point the subject became too overwhelmed with the atmosphere, they could choose to leave the space immediately.

Once the subject was informed of expectations, marker placement began. Reflective diodes were placed on anatomical landmarks previously determined through the Nexus "Plug-in-

Gait Lower Body AI" pipeline (Appendix E). Prior to data collection and after marker placement, researchers also gathered anthropometric data for each subject. Measurements included body mass (kg), height (mm), leg length (ASIS to medial malleolus, mm), knee width (calipers at joint line, mm), ankle width (calipers at malleoli, mm). Once these were collected, a subject profile was created and saved in the database. It is important to note that each subject was assigned a unique identifier for the remainder of the study to maintain subject privacy through data analysis.

Once all anthropometric information was collected, marker placement was complete and anatomical parameters were collected, the subject was moved into the space. The subject was placed in the center of space and instructed to perform a static post to calibrate their markers to space. Then, the subject was placed in the corner of the space out of view of the cameras. Subjects were all given the same verbal instructions on how to perform walking gait through the space (Appendix F). A series of colored red, yellow, and green lines of tape on the floor indicated when the subject was to begin walking and when to stop to correspond to the verbal instructions and provide a visual guide. There were three warm up rounds, then three rounds of gait cycle collection. The walking trials were completed on a flat, even surface in a controlled clinical environment.

The kinematic data collected during the trials included information about each subject's lower extremity (LE) movements, with a focus on ankle, knee, and hip movements and angles. Each subject's kinematic data was analyzed using Nexus 2.0 software. Of the three trials for each subject, the trial with the highest consistency of motion capture was selected for data analysis. Within the selected trial, the 2nd gait cycle for each subject was used for analysis. This cycle was determined to provide consistent representative gait data in the pilot testing. Due to the lack of force plates in the testing space, the researcher manually entered moments of heel strike and toe off for the 2^{nd} cycle of measurable gait in each trial for each subject using the Nexus 2.0 software marker trajectory feature. Then, the Plug-In Gait pipeline within Nexus 2.0 allowed for autocorrelation of all gait cycles, and calculated gait parameters for each LE, left (L) and right (R), which could be exported and compared. Additionally, the Plug-In Gait pipeline provided frame by frame kinematic joint angle amounts in X (sagittal), Y (Frontal), and Z (Transverse) planes for both left and right LE. Ankle plantarflexion and dorsiflexion, knee flexion and hyperextension, and hip flexion and extension kinematic values were derived from the X plane model outputs. Knee valgus and varus, and hip abduction and adduction kinematic values were derived from the Y plane model outputs. Hip internal and external rotation kinematic values were derived from the Z plane model outputs. The kinematic data from the second complete gait cycle was used for data analysis for each subject.

All values for both groups were entered into the Statistical Package for the Social Sciences (SPSS). Descriptive statistics for each sub variable were gathered using the Explore procedure for each group. Due to the small sample size, a Mann-Whitney U test was selected to analyze for differences between groups. The Mann-Whitney U test is a non-parametric test that does not require normal distribution for each group or equivalence of variance. All video data, 3D reconstructions, and .csv or Excel files were stored privately with password protection.

Results

All subject data was grouped into two groups. Two different areas of inquiry for the study were differences between groups in gait parameters and gait kinematics.

Gait Parameters

Table 1

Gait Parameters	BoBW		Contol		p value
	Mean	SD (±)	Mean	SD (±)	
L Cadence (step/min)	108.57	8.12	121.42	9.91	0.08
R Cadence (step/min)	106.5	6.61	122.5	10.23	0.06
L Walking speed (m/s)	0.99	0.13	1.3	0.11	0.02*
R Walking speed (m/s)	1.01	0.14	1.31	0.12	0.02*
L Stride time (s)	1.11	0.08	0.99	0.08	0.11
R Stride time (s)	1.13	0.07	0.99	0.09	0.06
L Step time (s)	0.57	0.05	0.51	0.07	0.39
R Step time (s)	0.56	0.06	0.48	0.01	0.04*
L Opp foot off (%)	13.02	5.18	4.92	1.28	0.02*
R Opp foot off (%)	10.94	2.87	3.18	0.81	0.02*
L Opp foot contact (%)	49.12	2.08	48.52	3.39	1.00
R Opp foot contact (%)	50.01	3.66	51.07	3.36	0.39
L Foot off (%)	60.26	3.66	59.47	2.82	1.00
R Foot off (%)	58.32	3.73	56.04	2.89	0.39
L single support (s)	0.4	0.05	0.44	0.03	0.19
R single support (s)	0.44	0.06	0.47	0.07	0.14
L double support (s)	0.27	0.09	0.16	0.06	0.08
R double support (s)	0.22	0.08	0.08	0.01	0.02*
L Stride length (m)	1.09	0.1	1.29	0.1	0.06
R Stride length (m)	1.13	0.1	1.29	0.07	0.06
L Step length (m)	0.57	0.06	0.67	0.1	0.15
R Step length (m)	0.56	0.05	0.62	0.05	0.04*
L Step Width (m)	0.23	0.05	0.18	0.06	0.24
R step width (m)	0.21	0.06	0.16	0.06	0.24

Note. The mean values and standard deviations for the all sub variables of gait parameters are displayed between groups. The two tailed significance p values for each sub variable between groups from the Mann-Whitney U test are listed. A statistically significant value of $p \leq .05$ was set for all data analysis (= $p \leq .05$).*

Descriptive statistic values for all subsets of different gait parameters are listed in Table 1 above. After completing a Mann-Whitney U test analysis of all the gait parameter data, the investigators identified values of statistically significant differences between the BoBW group and control group gait parameters for left walking speed, right walking speed, right step time, left opposite foot off, right opposite foot off, right double support, and right step length ($p \leq .05$).

Between the two groups, the BoBW group demonstrated a statistically significant decreased values for left ($p \leq .02$) and right ($p \leq .02$) limb walking speeds measured in meters traveled per second (Figures 1 & 2), and right limb step length ($p \leq .04$) measured in meters (Figure 3).

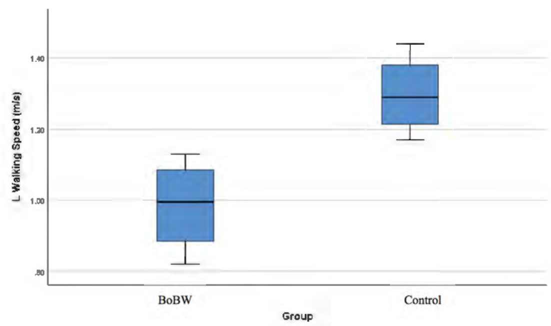


Figure 1. Box and Whisker plot which represents the mean values, distribution, and standard deviations for left limb walking speed (m/s) for each group.

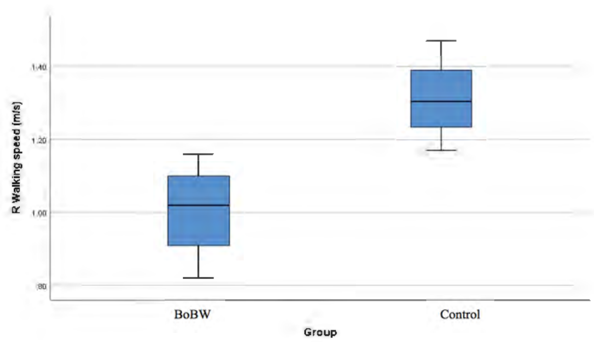


Figure 2. Box and Whisker plot which represents the mean values, distribution, and standard deviations for right limb walking speed (m/s) for each group.

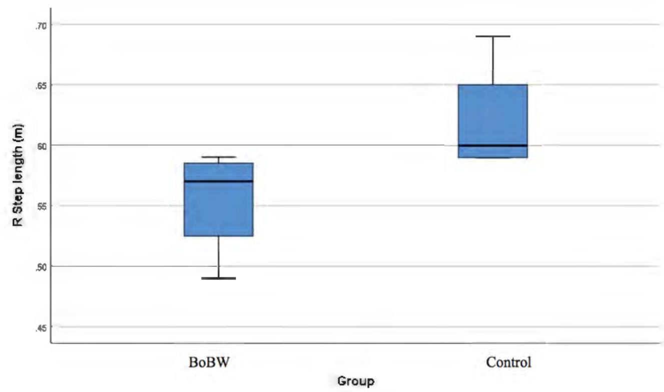


Figure 3. Box and Whisker plot which represents the mean values, distribution, and standard deviations for right limb step length (m) for each group.

The BoBW group also displayed statistically significant increase for the values of right limb step time ($p \leq .04$) measured in seconds (Figure 4), left ($p \leq .02$) and right ($p \leq .02$) limb opposite foot off percentages (Figures 5 & 6), and right limb double support ($p \leq .04$) measured in seconds (Figure 7).

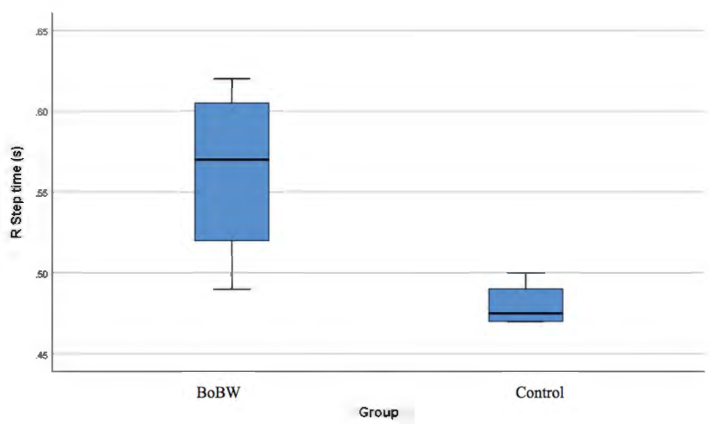


Figure 4. Box and Whisker plot which represents the mean values, distribution, and standard deviations for right limb step time (s) for each group.

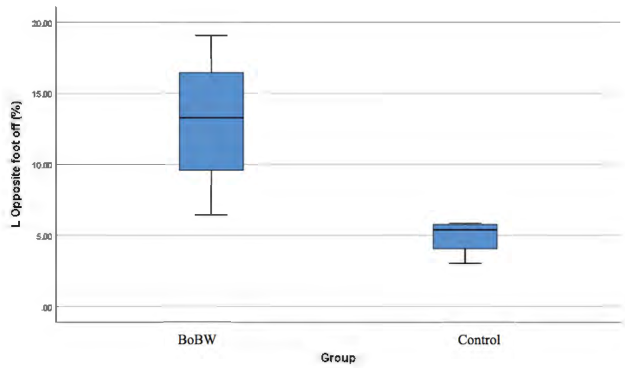


Figure 5. Box and Whisker plot which represents the mean values, distribution, and standard deviations of left limb opposite foot off percentage for each group.

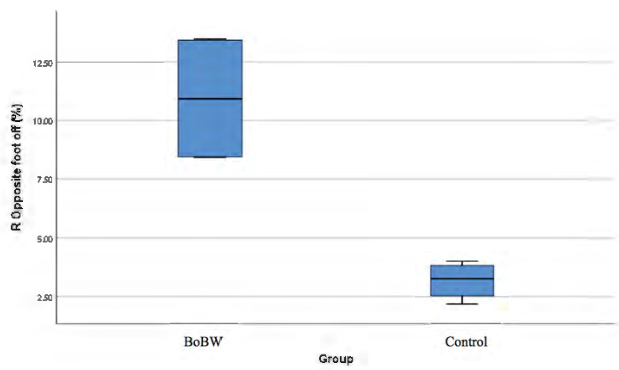


Figure 6. Box and Whisker plot which represents the mean values, distribution, and standard deviations for right limb opposite foot off percentage for each group.

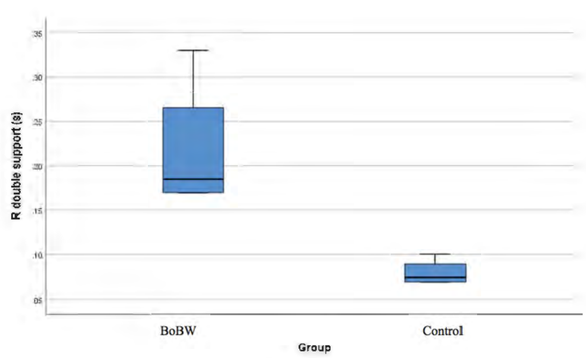


Figure 7. Box and Whisker plot which represents the mean values, distribution, and standard deviations for right limb double support (s) for each group.

For all other gait parameter values, there were no statistically significant differences between the BoBW and control groups identified. All gait parameter test statistics, U statistics, as well as the asymptotic significance (2-tailed) p-values from the Mann-Whitney U test are represented in Appendix G.

Kinematics

Table 2

Kinematics (deg)	BoBW		Contol		p value
	Mean	SD (±)	Mean	SD (±)	
L Max Dorsiflexion	16.7	5.58	15.29	5.56	0.39
R Max Dorsiflexion	15.27	1.54	14.85	4.46	1
L Max Plantarflexion	7.59	9.78	20.37	5.1	0.15
R Max Plantarflexion	10.5	4.63	20.17	9	0.08
L Max Knee Flexion	56.86	2.96	48.54	7.75	0.02*
R Max Knee Flexion	55.91	9.2	50.75	12.2	0.77
L Min Knee Flexion	1.55	3.4	-6.75	2.02	0.02*
R Min Knee flexion	-0.29	3.63	-4.85	5.45	0.25
L Knee Varus	13.47	8.07	16.38	7.8	0.77
R Knee Varus	3.65	5.18	10.91	11.84	0.39
L Knee Valgus	10.15	1.28	3.26	2.83	0.02*
R Knee Valgus	10.6	2.78	9.85	12.43	0.25
L max Hip Flexion	40.33	5.29	31.31	9.54	0.15
R max Hip Flexion	38.55	3.62	32.78	11.59	0.56
L Min hip flexion	1.61	7.74	-9.13	9.37	0.15
R min hip flexion	-0.22	6.21	-8.14	11.79	0.27
L Hip Abduction	4.56	1.93	7.18	2.43	0.08
R hip Abduction	3	3.08	5.64	4.89	0.56

L Hip Adduction	8.47	3.55	7.58	4.12	0.56
R Hip Adduction	11.36	2.27	9.12	4.35	0.25
L Hip Int. Rotation	11.92	12.96	16.57	10.16	0.56
R Hip Int. Rotation	15.59	7.76	6.67	28.09	0.77
L Hip Ext. Rotation	19.91	13.13	22.36	9.58	1
R Hip Ext. Rotation	7.28	12.52	14.58	19.5	0.39

Note. The mean values and standard deviations for the all sub variables of gait parameters are displayed between groups. The two tailed significance p values for each sub variable between groups from the Mann-Whitney U test are listed. A statistically significant value of $p \leq .05$ was set for all data analysis (= $p \leq .05$).*

The mean and standard deviation between groups for all maximum and minimum moments relative to gait for each joint are represented in Table 2 above. After completing a Mann-Whitney U test analysis of all the kinematic data, the investigators identified values of statistically significant differences between the BoBW group and control group kinematics of left knee maximum flexion ($p \leq .02$), left knee minimum flexion ($p \leq .02$), and left knee valgus ($p \leq .02$) angles. The BoBW group displayed statistically significant increased angles for these three kinematic values compared to the control group as shown in Figures 8-10.

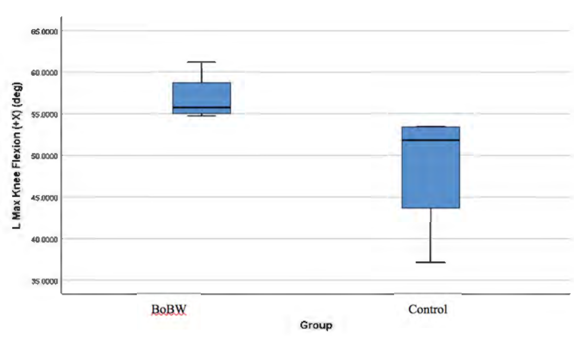


Figure 8. Box and Whisker plot which represents the mean values, distribution, and standard deviations for left knee maximum flexion (deg) for each group.

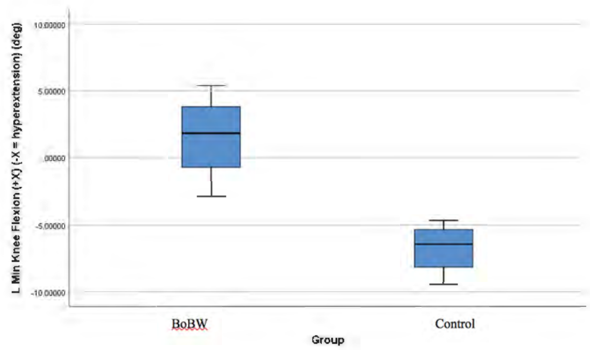


Figure 9. Box and Whisker plot which represents the mean values, distribution, and standard deviations for left knee minimum flexion (deg) for each group.

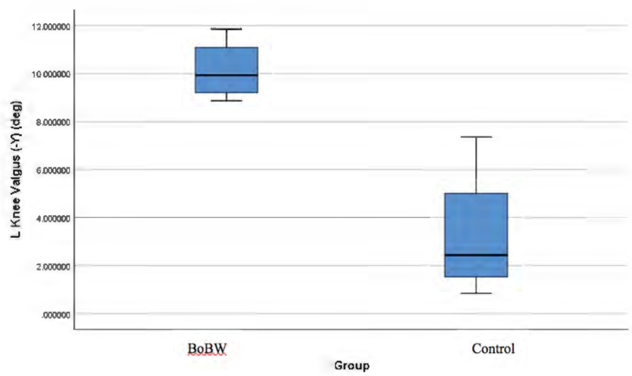


Figure 10. Box and Whisker plot which represents the mean values, distribution, and standard deviations for left knee maximum valgus (deg) for each group.

For all other kinematic angles, there were no statistically significant differences between the BoBW and control groups identified. All kinematic test statistics, U statistics, as well as the asymptotic significance (2-tailed) p-values from the Mann-Whitney U test are represented in Appendix H.

Discussion

The BoBW group displayed significantly decreased walking speeds for both left and right limbs. Confirming values for this gait abnormality were identified in the significant differences in right step length, right step time, left and right opposite foot off percentage, and right double support time between the BoBW group and the control and are consistent with decreased walking speeds of neurologic gait in certain populations of young adults (Almuhtaseb et al., 2014).

Walking speed represents distance traveled over time. Respectively, this means the BoBW subjects travelled less distance in the same amount of time as the control group, representing decreased speed. While there was not a significant difference between groups in either limb cadence, which represents number of strides per unit time, this parameter is related to speed and was found to be slightly decreased in the BoBW group, but not enough to achieve statistical significance.

The BoBW group presented with a significantly decreased right step length. This represents the distance between each ipsilateral foot contact in one gait cycle, or the distance between the initial right foot contact and the location of the following right foot contact. Left step length differences between groups were not found to be significant but were observed to include decreased values in the BoBW group compared to the control. Considering this, the decreased step lengths within the BoBW group represents less distance traveled in one cycle, thus relating to the observed significant decreased walking speed in the BoBW group as a decrease in distance traveled over time results in decreased velocity, or speed. This finding of decreased step length is associated clinically with a gait pattern that is often observed as "shuffling gait." In the literature that examines gait parameters that have been associated with increased fall risk, a decreased step length is consistently identified as a risk factor for falls.

Significantly increased right limb step time was found in the BoBW groups, which represented time between contralateral and the following ipsilateral foot contact. This finding signifies a larger amount of time occurred between the instance of left foot contact to the instance of right foot contact for the BoBW group than the control group. This can be related to the significantly decreased walking speed of both limbs found in the BoBW group. A larger step time represents increased time between each foot contact, and an increased time inversely relates to distance traveled, further explaining the decreased walking speeds observed in the BoBW group. The explanation for this difference has similar explanations as previously stated for walking speed and cadence such that there can be multiple contributing factors but there is an overall identifiable group difference. However, there were no significant values for left step time, or both left and right stride time. Stride time represents the time between successive ipsilateral foot strikes, or the time between left foot contact to the following left foot contact, or right foot contact to the following right foot contact. Since only right step time was found significantly longer, but left step time was not, this implies possible individual asymmetries in gait patterns relating to step time but should not be assumed for all members of the BoBW group. However, for all four parameters of right and left step and stride times, there were observed larger means within the BoBW group compared to the control group. While right step time is the only significant value, the increased values for all of these timed gait parameters were consistent with the significantly decreased left and right walking speed found in the BoBW group. In general, a decreased walking speed contributes to slower community ambulation, which in addition to being a safety risk, this can also impede one's ability to socialize with peers and can also impeded ability to complete job related tasks in a timely manner. As seen in Ratzon et al., (2010), young adults with disabilities displayed significant decreases in timed performance in Physical Work Performance Evaluation. This is consistent with the observed decreased walking speed and the possible negative contributions this characteristic could have in job related task performance.

Significantly larger values for left and right opposite foot off percentages were found in the BoBW group as compared to the control. Opposite foot off represents the time as a percentage of the gait cycle that the opposite toe off occurs. A higher value of opposite foot off percentage means the time of opposite toe off is later, representing larger time of double support within each gait cycle, or moments where both feet are in contact with the ground. Relatively, right double support time in the BoBW was found to be significantly higher than the control group. Double support represents the time from ipsilateral foot contact to contralateral foot off plus time from contralateral foot contact to ipsilateral foot off. For the BoBW group, the time from right foot contact to left foot off plus the time from left foot contact to right foot off was greater. While there were no significant differences between groups for left double support time, there were observed overall larger left double support times for the BoBW group compared to the control. The combination of significantly larger left and right opposite foot off percentages with significantly increased right double support time differences between the two groups represented the BoBW group spending more time in double support, or with both feet in contact of the ground. These values are representative of the relationship between stance versus swing. The BoBW subjects spent more time in stance phase of the gait cycle than the control. This means that they spent a decreased percentage of the gait cycle in the swing phase, which is where the corresponding limb is not in contact with the ground and is progressing forward to propel the body forward. Because the swing phase impacts the distance forward the subject travels, a decrease in swing phases will correspond to decrease distance traveled in one gait cycle, thus relating to decrease speed. Therefore, the combination of significantly increased values for opposite foot off and right double support in the BoBW group corresponds to the decreased walking speed within this group. Additionally, normal limb swing time produces the momentum driven quality of gait (Hazari et al., 2021). With this normal time in swing altered, it produces an overall need for greater energy expenditure by the BoBW students to perform simple automated tasks and activities of daily living.

When considering what contributes to decreased walking speeds, there may be possible limb movement limitations in the BoBW group's gait related to time during their normal walking patterns. This could be an effect of multiple factors on each subject's mobility, such as interaction of different physical characteristics and cognitive components, such as those represented in the literature review performed by Almuhtaseb et al. (2014). Due to the heterogeneous populations of the various intellectual disabled populations in the studies the review analyzed, gait differences such as decreased walking speed and cadence within all the studies had contributions ranging from obesity, to low muscle strength, to hypotonicity and more (Almuhtaseb et al., 2014). While our subjects in the BoBW program did not have exclusive diagnoses of intellectual disorders, the wide range of diagnoses within our population represents the diversity in diagnoses as presented in this review. This suggests that while there may not be one identifiable uniform contributing factor to the significantly decreased walking speed in all BoBW subjects, the overall observation is still notable as it describes a general gait abnormality identified within this population.

The BoBW group displayed slightly increased values of left and right step width as compared to the control. While these values are not found to be significant, there are clinical considerations for the observed increased values in step width as it applies to the BoBW population. A larger step width represents a greater horizontal distance between left and right foot contact. A larger step width represents a larger base of support, which is often observed in correction to balance instability in certain populations (Chambers & Sutherland, 2002). While not significant, if the BoBW students present with a larger base of support, this could represent a possible issue with balance in this population, which is directly related to injury risk as supported in the literature (Hausdorff et al., 2001).

Relating to gait kinematics, the BoBW displayed significantly larger values for the degree of left knee maximum flexion, left knee minimum flexion, and left knee valgus. A large value for the degree of maximum knee flexion means the maximum degree of knee flexion that occurred during one gait cycle in BoBW subjects was larger than the maximum degree of knee flexion during one gait cycle for one gait cycle. Similarly, a larger value for minimum knee flexion means that the minimum degree of knee flexion that occurred in one gait cycle for the BoBW subjects was larger than the control meaning the control actually experienced more knee hyperextension. A larger knee valgus degree represents increased frontal plane positioning away from midline for the BoBW subjects versus the control. Although these three dependent variables reached a level of statistical significance, the fact that all of the values were found on the left side seems to indicate that perhaps one particular subject may have had some left side asymmetry.

One limitation presented in the kinematic data analysis and interpretation was found to be a result of the absence of kinetic data during the study. While not statistically significant, the BoBW subjects displayed a decreased amount of maximum plantar flexion as compared to the control group. Without force plate data, we are unable to confirm, but can hypothesize that this represents a decreased value of plantar flexion force in the toe off moment, or moment of peak plantar flexion, in the gait cycle. The addition of force plates allows for kinetic, or force data to be paired with kinematic data to further explain gait differences or abnormalities (Eggleston et al., 2017). With the addition of kinetic data, observed angular differences between groups could have been explained by increased or decreased force values produced by each limb in different stages of the gait cycle. Kinetic data would have allowed for researchers to link values such as decreased peak plantarflexion to decreased force production and observe decreased gastrocnemius and soleus push off forces. Again, a sufficient force production in the plantarflexion moment of toe-off allows gait to be low expenditure and creates momentum. (Simonsen, 2014). These decreased kinetic values relate to observable energy generation differences between groups. Because we do not have kinetic values to pair with kinematic values in this study, the interpretation and assumption of kinematic differences is only hypothetical.

Limitations

One limitation of this study is the small number of participants available within the transition program. Similarly, completely random selection is unattainable as the subjects volunteered and were solicited from a highly specific group. Another limitation of this study is the lack of data collection from multiple transition programs.

Conclusion

The purpose of this study was to compile kinematic data on a population where there is little available data regarding gait characteristics. The results of this study provided insight into gait parameter differences between young adults with multiple disabilities and an age and gender matched control group. Values contributing to decreased walking speeds in the subjects of the BoBW population require further research to identify specific causes, but overall gait differences were identified. Abnormal gait parameter and kinematic information can be an indicator of injury and fall risk and can serve as a clear descriptor of mobility. In a population where physical demands may increase due to transition into the work force, it is important to identify if gait instability is an overarching issue or if there are any gait abnormalities within a group from this identified population. While additional research is required to understand these differences, the identified gait abnormalities within this study could be used to develop interventions that could be provided to such a group through established group fitness classes and the results could establish a means to advocate for continued therapy support for this population.

Appendix A – IRB Approval Form

OTTERBEIN UNIVERSITY

INSTITUTIONAL REVIEW BOARD

☒ Original Review
☐ Continuing Review
☐ Amendment

Dear Dr. Payne,

With regard to the employment of human subjects in the proposed research:

HS # 21/22-07
Payne & Rumbalski: Comparative Kinematic Gait Analysis in Adults with Multiple ...

THE INSTITUTIONAL REVIEW BOARD HAS TAKEN THE FOLLOWING ACTION:

☒ Approved
☐ Approved with Stipulations*
☐ Limited/Exempt/Expedited Review
☐ Disapproved
☐ Waiver of Written Consent Granted
☐ Deferred

*Once stipulations stated by the IRB have been met by the investigator, then the protocol is APPROVED.

1. As Principal Investigator, you are responsible for ensuring all individuals assisting in the conduct of the study are informed of their obligations for following the IRB-approved protocol.
2. It is the responsibility of the Principal Investigator to retain a copy of each signed consent form for at least four (4) years beyond the termination of the subject's participation in the proposed activity. Should the Principal Investigator leave the university, signed consent forms are to be transferred to the IRB for the required retention period.
3. If this was a limited, exempt, or expedited review, there is no need for continuing review unless the investigator makes changes to the proposed research.
4. If this application was approved via full IRB committee review, the approval period is one (1) year, after which time continuing review will be required.
5. You are reminded you must promptly report any problems to the IRB and no procedural changes may be made without prior review and approval. You are also reminded the identity of the research participants must be kept confidential.

Signed: Noam Shpancer Date: 9-27-21
IRB Chairperson

Appendix B – Best of Both Worlds "About" statement directly from the Best of Both Worlds Westerville official website

Westerville City Schools, in collaboration with Otterbein University, is a Transition Program for students with cognitive disabilities. For years, Westerville pupils had to travel to Ohio State or Columbus State to access proper Transition Programs. At a cost savings of more than $200,000, the "Best of Both Worlds" program allows local students to access Transition Services in their home community.

Students in the program will have work experiences on Otterbein's Campus and in Westerville; participate in activities on Otterbein Campus with Otterbein students; and practice daily living skills throughout the local community. They will gain skills for independence while experiencing college life at Otterbein University.

We provide the appropriate transition and educational experiences for students by involving them in a variety of activities including:

-Direct instruction in important life skills.

-Self-determination and self-advocacy to increase independence in the home, work environment, and community.

-Community based work experiences to help with employment skills that can generalize to a variety of work places.

-Recreation and leisure activities to improve quality of life and increase community integration at all levels.

Appendix C – Student Participation Consent Form

Student Participation Consent Form

I consent to participating in research entitled: Comparative Kinematic Gait Analysis in Adults with Multiple Disabilities

Dr. Shelley Payne (Principal Investigator) or her authorized representative has explained the purpose of the study, the procedures to be followed, and the expected duration of my participation.

I acknowledge that I have had the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full satisfaction. Furthermore, I understand that I am free to withdraw consent at any time and to discontinue participation in the study without prejudice to me.

Finally, I acknowledge that I have read and fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date: ______________________________

Participant Signature: ________________________

Person Authorized to Consent for Subject (if necessary): ________________________

Witness: ______________________

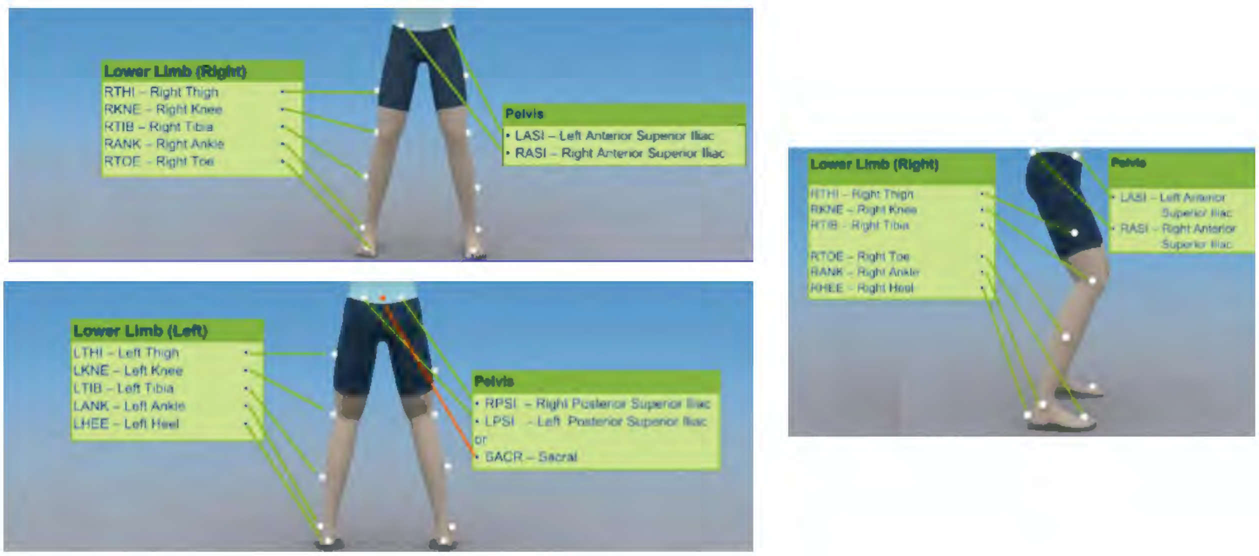
Appendix D – Solicitation Statement

Greetings,

We are contacting you all regarding your child's potential participation in a study being conducted this winter in Otterbein's newly instated Biomechanics Institute! This lab allows us to use 3D motion capture technology to analyze each subject's lower limb movements, with a focus on ankle, knee, and hip movements and angles. This study is looking to examine walking-gait characteristics in young adults with multiple disabilities in the BoBW program as related to other college-aged students at Otterbein University. To participate in this study, your student would come into our lab at the Point on Otterbein's campus for a one-time observational session. During this session, they would have reflective markers placed on their hips, legs, and feet. They would be instructed to walk around the data collection space during data collection for 3 trials consecutively, each that lasts about under a minute. The total session would be no longer than 2 hours of participation. After the in-person study, your child's kinematic data would be analyzed and compared. All students' identities will remain anonymous throughout the research process. Attached is a consent form that will also be sent home with your child that will need to be filled out to allow for their participation in the study.

Thank you for your consideration!

Appendix E – Marker placement for Plug-in Gait lower body model



Appendix F – Verbal Instructions

Verbal Instructions for Data Capture:

1) "First, place both of your feet behind the big red line on the floor"

2) "When you hear me say the words 'Begin walking', you can start to walk towards the green line on the ground in front of you at your normal walking pace"

3) "Once you pass the green line, continue to walk like normal across the whole room towards the yellow line"

4) "Once you get to the yellow line, you can stop when you pass it. I will also remind you to stop once you get to the yellow line."

6) "Once I tell you to stop, you can walk back to the red line."

7) "When you are in place behind the red line, I will ask you if you are ready to begin again"

Instructions are repeated before each trial while the subject is in place at the red line. Once the subject confirms readiness behind the red line, the data capture begins, and the researcher states the initiation prompt: "Begin walking".

Appendix G - Test statistics table showing comparison of Gait Parameter values between groups from Mann-Whitney U test

Test Statistics[a]

	L Cadence (step/minute)	R Cadence (step/minute)	L Walking Speed (m/s)	R Walking speed (m/s)	L Stride time (s)	R Stride time (s)	L Step time (s)	R Step time (s)	L Opposite foot off (%)	R Opposite foot off (%)	L Opposite foot contact (%)	R Opposite foot contact (%)
Mann-Whitney U	2.000	1.500	.000	.000	2.500	1.500	5.000	1.000	.000	.000	8.000	5.000
Wilcoxon W	12.000	11.500	10.000	10.000	12.500	11.500	15.000	11.000	10.000	10.000	18.000	15.000
Z	-1.732	-1.899	-2.309	-2.309	-1.597	-1.899	-.866	-2.033	-2.309	-2.309	.000	-.866
Asymp. Sig. (2-tailed)	.083	.058	.021	.021	.110	.058	.386	.042	.021	.021	1.000	.386
Exact Sig. [2*(1-tailed Sig.)]	.114[b]	.057[b]	.029[b]	.029[b]	.114[b]	.057[b]	.486[b]	.057[b]	.029[b]	.029[b]	1.000[b]	.486[b]

	L Foot off (%)	R Foot off (%)	L single support (s)	R single support (s)	L double support (s)	R double support (s)	L Stride length (m)	R Stride length (m)	L Step length (m)	R Step length (m)	L Step Width (m)	R step width (m)
Mann-Whitney U	8.000	5.000	3.500	3.000	2.000	.000	1.500	1.500	3.000	1.000	4.000	4.000
Wilcoxon W	18.000	15.000	13.500	13.000	12.000	10.000	11.500	11.500	13.000	11.000	14.000	14.000
Z	.000	-.866	-1.315	-1.488	-1.753	-2.337	-1.888	-1.888	-1.452	-2.071	-1.169	-1.162
Asymp. Sig. (2-tailed)	1.000	.386	.189	.137	.080	.019	.059	.059	.146	.038	.243	.245
Exact Sig. [2*(1-tailed Sig.)]	1.000[b]	.486[b]	.209[b]	.209[b]	.114[b]	.029[b]	.057[b]	.057[b]	.200[b]	.057[b]	.343[b]	.343[b]

a. Grouping Variable: Group

b. Not corrected for ties.

Appendix H - Test statistics table showing comparison of Kinematic values between groups from Mann-Whitney U test

Test Statistics[a]

	L Max Dorsiflexion (+X) (deg)	R Max Dorsiflexion (+X) (deg)	L Max Plantarflexion (-X) (deg)	R Max Plantarflexion (-X) (deg)	L Max Knee Flexion (+X) (deg)	R Max Knee Flexion (+X) (deg)	L Min Knee Flexion (+X) (-X = hyperextension) (deg)	R Min Knee flexion (+X) (-X = hyperextension) (deg)	L Knee Varus (+Y) (deg)	R Knee Varus (+Y) (deg)	L Knee valgus (-Y) (deg)	R Knee valgus (-Y) (deg)	L max Hip Flexion (+X) (deg)
Mann-Whitney U	5.000	8.000	3.000	2.000	.000	7.000	.000	4.000	7.000	5.000	.000	4.000	3.000
Wilcoxon W	15.000	18.000	13.000	12.000	10.000	17.000	10.000	14.000	17.000	15.000	10.000	14.000	13.000
Z	-.866	.000	-1.443	-1.732	-2.309	-.289	-2.309	-1.155	-.289	-.866	-2.309	-1.155	-1.443
Asymp. Sig. (2-tailed)	.386	1.000	.149	.083	.021	.773	.021	.248	.773	.386	.021	.248	.149
Exact Sig. [2*(1-tailed Sig.)]	.486[b]	1.000[b]	.200[b]	.114[b]	.029[b]	.886[b]	.029[b]	.343[b]	.886[b]	.486[b]	.029[b]	.343[b]	.200[b]

	R max Hip Flexion (+X) (deg)	L Min hip flexion (+X) (-X = hip extension) (deg)	R min hip flexion (+X) (-X = hip extension) (deg)	L Hip Abduction (-Y) (deg)	R hip Abduction (-Y) (deg)	L Hip Adduction (+Y) (deg)	R Hip adduction (+Y) (deg)	L Hip Internal Rotation (+Z) (deg)	R Hip internal Rotation (+Z) (deg)	L Hip External Rotation (-Z) (deg)	R Hip External Rotation (-Z) (deg)
Mann-Whitney U	6.000	3.000	4.000	2.000	6.000	6.000	4.000	6.000	7.000	8.000	5.000
Wilcoxon W	16.000	13.000	14.000	12.000	16.000	16.000	14.000	16.000	17.000	18.000	15.000
Z	-.577	-1.443	-1.155	-1.732	-.577	-.577	-1.155	-.577	-.289	.000	-.866
Asymp. Sig. (2-tailed)	.564	.149	.248	.083	.564	.564	.248	.564	.773	1.000	.386
Exact Sig. [2*(1-tailed Sig.)]	.686[b]	.200[b]	.343[b]	.114[b]	.686[b]	.686[b]	.343[b]	.686[b]	.886[b]	1.000[b]	.486[b]

a. Grouping Variable: Group

b. Not corrected for ties

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