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The effect of backpack load on trunk kinematics of imitated pathological gait: a case study

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THE EFFECT OF BACKPACK LOAD ON TRUNK KINEMATICS OF IMITATED PATHOLOGICAL GAIT: A CASE STUDY

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Tables and Figures

The Effect of Backpack Load on Trunk Kinematics of Imitated Pathological Gait: A Case Study

Abstract

Background: It is well documented that loaded backpacks affect the biomechanics of gait in both children and adults. Minimal information is available with regard to the effects of backpacks on the biomechanics of gait in individuals with clinical gait abnormalities, such as those seen in cerebral palsy. Healthy, non-clinical populations can be taught how to 'imitate' typical gait abnormalities in order to study various experimental interventions without enlisting clinical patients. The objective of this study was to determine the acute effect of backpack load on kinematics of the trunk during typical and imitated pathological gait. **Methods:** COVID 19 restrictions precluded the use of multiple subjects as originally planned, therefore in response to those limitations only one healthy female (25 yrs) performed two trials each of 4 gait styles (typical, crouch, toe, and jump gait), under unloaded and backpack-loaded conditions. Trials were recorded and digitized using a 12-camera motion analysis system. The loaded conditions utilized a student backpack weighted at 20% of the participant's body weight (11.8 kg) using various sized small weights. Kinematics of the trunk including mean lateral trunk tilt, mean trunk inclination and mean anterior-posterior pelvic tilt, along with select spatio-temporal variables, were compared across loading conditions and among each gait type. **Results:** The kinematic variables of trunk tilt and pelvic tilt were exaggerated under the loaded conditions across pathological gait patterns. Double support time increased while single support time decreased. **Significance:** This case-study investigation was conducted as a hypothesis-generating study for kinematic variables of the trunk under load in populations exhibiting the studied gait patterns. The findings warrant further research in reference to load carriage parameters.

Electromyographic testing may be beneficial to add to the current test battery in order to capture

additional compensatory muscle actions that may contribute to overall dynamic motor control of the participant. Future research should contribute to better informed carriage practices for individuals with pathological gait patterns seen in cerebral palsy and toe walking.

Introduction

Wearing loaded backpacks is often criticized as leading to musculoskeletal fatigue or pain after long-term carriage. Many researchers hypothesize that this long-term carriage leads to injury or musculoskeletal problems (Brackley & Stevenson, 2004; Lai et al., 2011). In the short-term, it appears that backpack carriage, particularly heavy pack carriage (typically defined as between 15 and 20% of an individual's bodyweight (Brackley & Stevenson, 2004)), may cause kinematic changes in gait which have been associated with musculoskeletal injury and back pain (Dorji, Tamang, Yoezer, & Wangdi, 2019; Hong & Cheung, 2003; Kinoshita, 1985; Layuk, Martiana, & Bongakaraeng, 2020; López Hernández, Caparó Ferré, Giné Martí, & Salvat Salvat, 2020; Martin & Nelson, 1986; Perrone, Orr, Hing, Milne, & Pope, 2018; Singh & Koh, 2009). Though long-term data have not been reported regarding the negative health impacts of backpack loads causing kinematic changes of this type, currently, researchers recommend that heavy backpack loads be avoided by children so as to not place them at unnecessary risk of injury (Brackley & Stevenson, 2004).

There exists some overlap between altered trunk kinematics from backpack carriage and altered kinematics due to pathology such as cerebral palsy. Areas of concern which span both categories are anterior trunk tilt, anterior pelvic tilt and trunk obliquity affecting individuals diagnosed with cerebral palsy (Heyrman et al., 2014; Kiernan, O'Sullivan, Malone, O'Brien, & Simms, 2018) and those carrying loaded backpacks (Hong & Cheung, 2003; Kinoshita, 1985; Martin & Nelson, 1986; Singh & Koh, 2009). These three gait characteristics are concerning to both researchers and clinicians as they have been linked with musculoskeletal pathology and back pain (Kistner, Fiebert, Roach, & Moore, 2013; Sharan, Mohandoss, Ranganathan, Makkuva clude, & Kavoor, 2015; Strube et al., 2017).

Sharan et al. (2015) conducted a systematic review of 25 studies to determine the most impactful ergonomic risk factors associated with backpack carriage and concluded that increased anterior trunk tilt resulting from the load on the back was the primary cause for reports of back pain. Kistner et al. (2013) conducted a study examining the postural compensations and complaints that occurred in children carrying loaded backpacks and found that carrying a loaded backpack significantly increased anterior pelvic tilt along with increased complaints of pain in the neck, shoulders, and mid-back. Both a more anteriorly tilted trunk and an anteriorly tilted pelvis can work in tandem to create a milieu for back pain to occur by increasing lumbar torque, placing greater stress on the muscles of the lower back and intervertebral discs (Strube et al., 2017).

Cerebral palsy (CP) is one of the most common diagnoses in which patients undergo clinical gait analysis. From these analyses several consistent pathological gait patterns have been identified as compensatory gait types common in individuals with CP (Attias et al., 2015). Three of the most common gait patterns observed in connection with CP are toe walking, crouch gait, and jump gait (Balzer, Schelldorfer, Bauer, & van der Linden, 2013; Rezgui, Megrot, Fradet, & Marin, 2013). Toe walking is characterized by a bilateral equinus (plantarflexion of the ankle) of 30º to 60º, with weight bearing on the balls of the feet (Sala, Shulman, Kennedy, Grant, & Chu, 1999). Characteristics of jump gait include increased hip flexion, knee flexion and ankle plantarflexion of greater than 90 º, while characteristics of crouch gait include increased hip flexion, knee flexion, and ankle dorsiflexion of less than 90º (Miller, 2018). Figure 1 provides a sagittal plane illustration of the three pathological CP gait patterns being examined in this study.

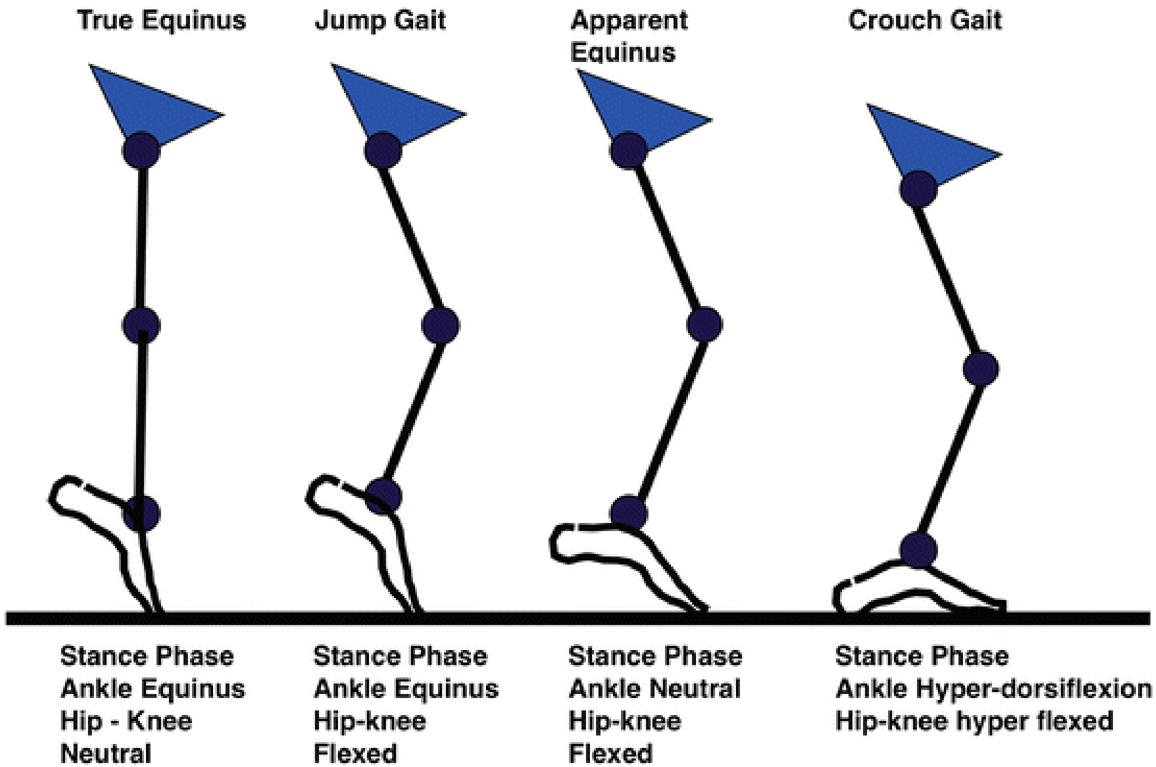

Figure 1. Sagittal plane illustration of typical CP pathological gait patterns (Miller, 2018)

Upon examination of pathological gait kinematics resulting from CP and potentially disordered gait kinematics resulting from heavy backpack carriage, researchers have identified a few areas of concern that are consistent between both fields of gait study. However, backpack carriage has been analyzed among a variety of healthy and able-bodied populations yet has been only recently studied in pathological populations such as individuals with CP (Lai et al., 2011). Lai et al. (2011) completed a study which consisted of nine adults with CP who suffered from low back pain, and who wore a lightly-weighted backpack for 60 minutes, four days a week. The participants reported a significant reduction in low back pain immediately after wear. Researchers attributed the reduction in back pain to the backpack acting to relieve tension in the back, specifically back extensors, during the time the load was carried.

Similar to studies that have examined the negative impact of backpack load on healthy individuals, studies that have examined CP gait have also identified anterior trunk tilt, lateral trunk obliquity, and anterior pelvic tilt as potential negatively impactful factors associated with CP (Abbasi, Rojhani-Shirazi, Razeghi, & Raeisi Shahraki, 2018; Heyrman et al., 2014; Kiernan, Malone, O'Brien, & Simms, 2016; Kiernan et al., 2018; Malone, Kiernan, French, Saunders, & O'Brien, 2016; Rethwilm, Böhm, Dussa, & Federolf, 2019). Kinematic parameters assessed from the trunk and spine of 92 children with CP were analyzed from sagittal, transverse, and coronal planes (Attias et al., 2015). Greater levels of impairment were found to be associated with an increased range of motion of the trunk. A separate study utilized 52 participants with CP and analyzed kinematics of the lower limb and thorax and kinetics of the trunk, specifically forces observed at L5-S1 of the spine (Kiernan et al., 2018). Trunk obliquity was analyzed both with respect to the room and with respect to the pelvis as a kinematic variable. Researchers discovered that in each gait pattern analyzed, trunk obliquity increased with the greatest increase observed in Type 3 gait pattern, characterized by a distinct pelvic drop and excessive lateral lean of the trunk. Rethwilm and colleagues (2019) completed a retrospective study analyzing 255 children and adolescents with bilateral CP in order to determine if excessive trunk lean in patients with CP is part of an underlying biomechanical mechanism. Researchers analyzed trunk obliquity along with nine angles derived from the gait profile score. These participants were further categorized into participants with and without excessive trunk lean. Excessive trunk lean was determined when trunk obliquity exceeded three standard deviations, determined by typically developing population of norms. Results did not clearly identify excessive trunk lean to be associated with other kinematic deviations and therefore it could not be concluded that trunk obliquity was an underlying biomechanical mechanism associated with CP (Rethwilm et al., 2019). However, findings were in alignment with previous literature (Attias et al., 2015) which found that trunk obliquity increased along with the amount of impairment an individual with CP exhibited.

One issue in conducting studies on pathological gait patterns associated with CP is the lack of access to large populations of individuals with CP who exhibit the exact pathological gait patterns researchers wish to examine. Researchers have recently demonstrated that healthy, able-bodied individuals can ambulate using a mimicked pathological gait pattern associated with CP with a high degree of accuracy when familiarized with the execution of the gait pattern (Balzer et al., 2013; Fox, Carty, Modenese, Barber, & Lichtwark, 2018; Rezgui et al., 2013). Some concerns regarding this methodological approach suggest that generalizability of conclusions from imitated clinical gait could be limited since many pathological CP gait types are caused by underlying physiological and neurological issues which cannot be replicated in healthy populations. However, imitated CP gait can provide valuable additional information on voluntary modified posture and compensations which occur as a result of altering the typical gait pattern (Rezgui et al., 2013).

Statement of the Problem

As there have been concerns leading to the analysis of backpack load, previous research has resulted in percent bodyweight recommendations in healthy, able-bodied populations. Researchers and the public should be justifiably concerned about backpack load among those whom exhibit pathological gait patterns, perhaps more so. Understanding the biomechanical implications of backpack load on pathological gait may contribute to the understanding of gait kinematics under external load (Brackley & Stevenson, 2004) and provide a rationale for making recommendations for backpack loads in individuals exhibiting a particular pathological gait.

Researchers have placed a great deal of focus on the impact of backpack loads in promoting increased anterior trunk tilt, lateral trunk tilt, and anterior pelvic tilt, (Hong & Cheung, 2003; Kinoshita, 1985; Martin & Nelson, 1986; Singh & Koh, 2009) and these same kinematic measures have been identified as risk factors for musculoskeletal issues that individuals with CP are already particularly susceptible to (Heyrman et al., 2013; Heyrman et al., 2014; Kiernan et al., 2018). This being the case, research into the effect of carried backpack loads on pathological gait should begin by analyzing these three kinematic variables of the trunk.

Accommodations and compensatory actions for a pathological gait are often analyzed in the available literature (Attias et al., 2015; Heyrman et al., 2014; Kiernan et al., 2018; Saavedra & Woollacott, 2015). Likewise, the effect of load on typical gait has been examined several times in the past (Brackley & Stevenson, 2004; Connolly et al., 2008; Hong & Cheung, 2003; Kiernan et al., 2016; Kiernan & O'Sullivan, 2019; Kinoshita, 1985; Kurz, Arpin, & Corr, 2012; Malone et al., 2016; Martin & Nelson, 1986; Ozgul et al., 2012; Park et al., 2014; Singh & Koh, 2009). However, an area that has yet to be analyzed is the effect of maximum recommended backpack load on populations exhibiting pathological gait. Populations who experience pathological gait still attend public schools and may carry a backpack, exposing themselves to many of the same risks that healthy individuals experience. Observing the effects of load on pathological gait will help health professionals understand any changes that may occur in unloaded versus loaded variations of gait patterns. This information may be beneficial to translate into how this may affect a person's daily life given backpack carriage for school attendance or other reasons.

Materials and Methods

The current case study presented was conducted as pilot work for the originally-approved thesis proposal. The full experiment data collection was set to take place March 23, 2020 – April 10, 2020 with a projection of at least 16 participants for proper statistical power. As a result of the COVID-19 pandemic, in-person research became prohibited and the government enacted rules of social distancing. Therefore, this thesis represents a case-study conducted utilizing the methods originally approved by the thesis committee. This case study was completed at Shriners Childrens' Motion Analysis Center, Spokane, as an internship requirement and as the pilot study for a proposed thesis by the primary author.

Participant

One healthy adult female aged 25 years (mass 59 kg; height 1.6 m), free of neurological or orthopedic abnormality, was recruited for this case study. The participant was asked to perform trials of typical gait and imitate three separate pathological gait patterns: toe walk, jump gait, and crouch gait patterns which are often observed in diagnosis of cerebral palsy.

Measurement and Procedure

Verbal consent was obtained from the participant after the researcher explained the experimental protocol. Anthropometric measurements were then collected. One measurement was collected for height (m), mass (kg), anterior superior iliac spine (ASIS) to ASIS distance (mm), and bilateral measurements of leg length, knee width, and ankle width (all in mm) (Davis, Õunpuu, Tyburski, & Gage, 1991). Knee width while wearing a brace was also measured. Weight measurement was obtained with a standard physician's scale, height and leg length utilized a Seca stadiometer model 216 and measuring tape respectively. Seritex GPM calipers model 106 were used to obtain ASIS to ASIS distance, knee and ankle width. The 3D motion capture procedure included 21 reflective markers adapted from a Newington Childrens marker set (Davis et al., 1991). Eighteen markers were used to define the Vicon Plug-In-Gait model for the lower extremity, while an additional three markers help create the trunk. Markers were sized 9 mm for the feet and 14 mm for the legs and trunk. A 12-camera VICON Vantage v16 motion capture system (VICON, Oxford, UK) was used to capture kinematic data at a frequency of 100 Hz. The 12 cameras were spaced equally around the room. A dynamic wand calibration was completed prior to data collection. Proper calibration was ensured by limiting axis error to less than 5mm for x,y, and z axis measurements.

Proper marker placement was assured by using a knee alignment device (KAD) during a static trial (Davis et al., 1991). Marker placement was completed by an experienced researcher (3+ yrs). Markers were attached to the skin with double sided stickers. The participant wore athletic, dark, tight-fitting clothing free of reflective material. For consistency, the participant wore an RCAI post-surgical brace ("Knee and Leg Orthoses," n.d.) on both legs for all trials under each walking condition The backpack was worn so that the marker placed at C7 was not covered and the backpack straps fit comfortably over both shoulders. Ankle weights were used to load the backpack with 11.8 kg, equal to twenty percent bodyweight of the participant. During imitated gait trials, the researcher adjusted the knee brace to limit knee extension to 40° while allowing additional flexion, consistent with previous research on imitation of pathological gait (Balzer et al., 2013). In order to properly capture lower back markers, posterior superior iliac spine (PSIS), extenders were placed on the markers and worn for all conditions (Davis et al., 1991)(see figure 2).

Figure 2. Left: Frontal view of static take unloaded. Middle: Sagittal view static unloaded. Right: Posterior loaded static

Instructions were given by the researcher for each simulated gait pattern, and an opportunity to practice the imitation of the pathological gait patterns was allowed before each new gait simulation until the participant felt confident in imitating the gait pattern requested (Rezgui et al., 2013). Each gait pattern was performed at a comfortable, self-selected walking speed. Two gait trials were completed for each walking condition. Sagittal, frontal, and transverse planes of motion of the trunk were analyzed.

Data Analysis

As this was an explorative case study, no tests were performed to analyze differences in means. Kinematic data were captured and exported using VICON Nexus 2.9.3 software (VICON, 2019). Data from each trial were interpolated to fill any marker gaps and smoothed using a fourth-order, zero lag, low-pass Butterworth filter. Smoothed data were converted to 3D angles using Euler angles (Greenwood, 1965; Kadaba, Ramakrishnan, & Wootten, 1990). Two trials were averaged for each gait type and condition. Segment rotations were determined relative to the laboratory space. Angles were calculated for rotation (z), obliquity (y), and tilt (x). Trunk tilt and pelvic tilt were defined in relation to the x-axis, while trunk obliquity was defined in relation to the y-axis (see figure 3) (Davis et al., 1991). Nexus Report Generator was used to graph trunk tilt, pelvic tilt and trunk obliquity angles at each phase of the gait cycle along with their mean data (see figure 4). Standard spatio-temporal values including velocity, stride length, step length, and step time, and gait cycle variables, single support and double support time were reported. To analyze the temporal and gait cycle variables in the loaded and unloaded conditions of specific types of gait, a percent difference comparison was used to report the amount of change between unloaded and loaded conditions.

Trunk Tilt (Sagittal)	Pelvic Tilt (Sagittal)	Trunk Obliquity (Posterior)

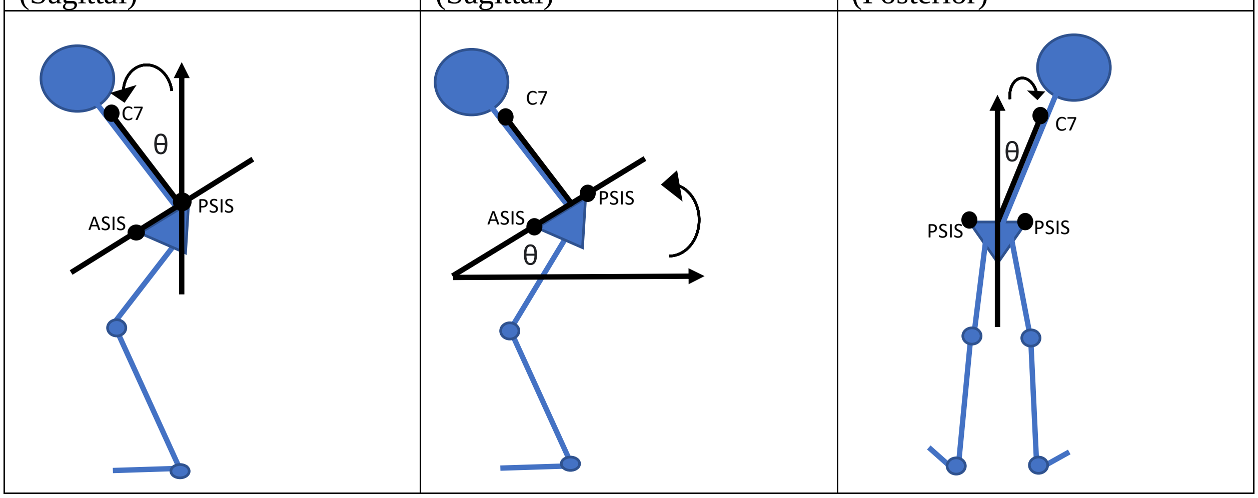

Figure 3. Angles defined for trunk tilt, pelvic tilt, and trunk obliquity.

Results

Mean trunk kinematics in unloaded and loaded gait types are displayed in Table 1. Loaded conditions resulted in an increase in trunk tilt for all gait types while pelvic tilt also increased under load for all gait types. Trunk obliquity remained relatively unchanged. Figure 4 displays graphical representations of trunk kinematics for the aforementioned variables with unloaded conditions displayed in solid color lines while loaded conditions are displayed in the boxed lines. Table 2 compares spatio-temporal values. Under the loaded conditions, double support time increased while single support time decreased. Velocity, stride length, and step length also decreased under load.

Table 1

Mean trunk kinematics by gait type.

Gait	Trunk Tilt (°)		Pelvic Tilt (°)		Trunk Obliquity (°)	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**
Typical	9.1	9.2	8.6	8.7	1.6	-1.8
Typical Loaded	16.8	17.6	10.2	11.2	0.9	-0.8
Toe Walk	12.6	12.6	14.7	14.3	1.7	-1.8
Toe Walk Loaded	22.7	22.4	18.9	18.8	1.6	-1.4
Crouch	12.4	12.6	17.0	16.9	0.8	-0.9
Crouch Loaded	21.2	20.8	18.4	18.1	0.6	0.0
Jump	12.3	12.7	14.5	14.5	1.1	-1.5
Jump Loaded	22.6	22.8	18.7	18.7	2.2	-1.7

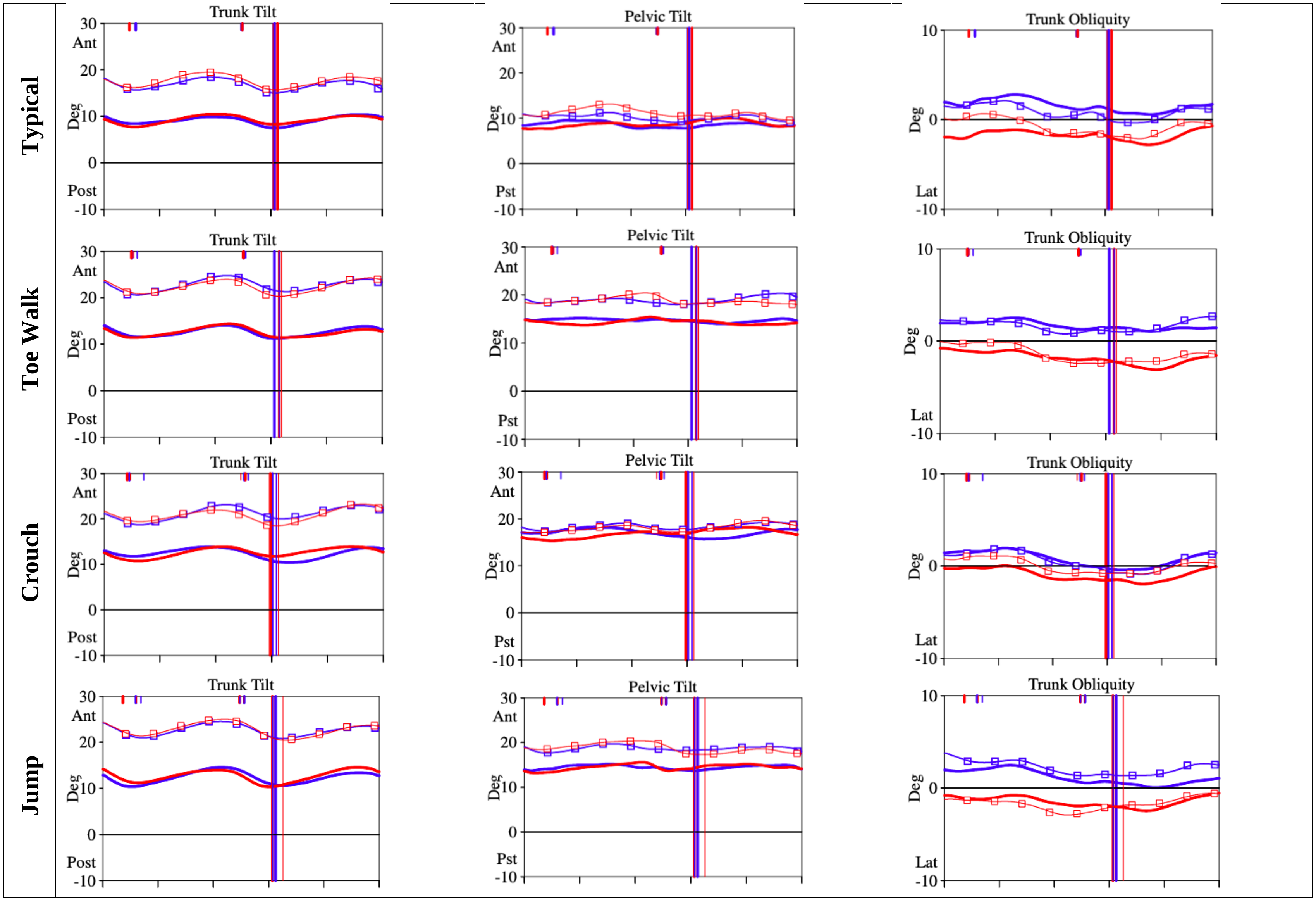

Figure 4. Trunk kinematics normalized to 100% of the gait cycle. Red line = right side, blue line = left side. Solid line = unloaded condition, boxed line = 20% bodyweight load. The vertical line represents toe off and the tick marks represent opposite foot off and opposite foot contact respectively.

Table 2. Spatio-temporal variables by gait type and condition. Percent difference (% Diff) between conditions of load also displayed.

	Left Side			Right Side		
	Typical	**Typical Loaded**	***% Diff***	**Typical**	**Typical Loaded**	***% Diff***
Velocity (m/sec)	1.08	1.08	***0***	1.09	1.11	***1.83***
Stride Length (m)	1.18	1.20	***1.69***	1.18	1.20	***1.69***
Step Length (m)	0.58	0.59	***1.72***	0.60	0.61	***1.67***
Step Time (sec)	0.55	0.56	***1.82***	0.54	0.55	***1.85***
Single Support	38.4%	38.0%	***1.05***	40.6%	40.3%	***0.74***
Double Support	23.0%	22.7%	***1.32***	21.8%	20.5%	***6.34***
	Toe Walk	**Toe Walk Loaded**	***% Diff***	**Toe Walk**	**Toe Walk Loaded**	***% Diff***
Velocity (m/sec)	1.01	0.99	***2.02***	1.03	0.98	***5.1***
Stride Length (m)	1.08	1.05	***2.86***	1.08	1.06	***1.89***
Step Length (m)	0.55	0.54	***1.85***	0.53	0.52	***1.92***
Step Time (sec)	0.53	0.52	***1.92***	0.52	0.54	***3.85***
Single Support	40.1%	39.0%	***2.82***	40.2%	39.1%	***2.81***
Double Support	21.3%	24.0%	***12.68***	22.8%	24.8%	***8.77***
	Crouch	**Crouch Loaded**	***% Diff***	**Crouch**	**Crouch Loaded**	***% Diff***
Velocity (m/sec)	1.00	0.95	***5.26***	1.00	0.96	***4.17***
Stride Length (m)	1.06	1.06	***0***	1.08	1.05	***2.86***
Step Length (m)	0.52	0.51	***1.96***	0.56	0.55	***1.82***
Step Time (sec)	0.53	0.54	**1.89**	0.54	0.56	**3.70**
Single Support	41.2%	37.4%	***10.16***	42.4%	39.4%	***7.61***
Double Support	19.1%	24.4%	***27.75***	17.2%	23.1%	***34.3***
	Jump	**Jump Loaded**	***% Diff***	**Jump**	**Jump Loaded**	***% Diff***
Velocity (m/sec)	1.01	0.96	***5.21***	0.98	0.93	***5.38***
Stride Length (m)	1.07	1.01	***5.94***	1.06	1.00	***6.00***
Step Length (m)	0.55	0.49	***12.24***	0.51	0.50	***2.00***
Step Time (sec)	0.52	0.53	***1.92***	0.55	0.52	***5.77***
Single Support	39.2%	35.8%	***9.5***	42.2%	38.8%	***11.05***
Double Support	23.3%	25.7%	***10.3***	19.1%	26.4%	***38.22***

Discussion

This study aims to begin to fill the current gap in the literature by describing the effect of load on pathological gait. Results will be hypothesis generating in order to provide the questions which further inquiry could potentially be based upon, and therefore conclusions will not be gathered from the results of the current case-study. All results should be viewed as preliminary and not inferential. Case study results are an invaluable asset in research due to their ability to explore a research question in order to better refine the question, particularly in clinical research where traditional study designs may not be applicable (Crowe et al., 2011). Kinematic adaptations observed in the current study seem to be consistent with previous literature. Imitation of pathological gait has not studied the effect of load or kinematics of the trunk and pelvis, as the current case study had done. The adaptations noted may be common compensatory mechanisms to adapt to the added load on the body in order to increase gait stability and reduce mechanical stress to the body (Singh & Koh, 2009). For purposes of discussion, kinematics will be discussed using the maximum mean value from either right or left limb, whichever is of larger absolute value.

One mechanism adopted in order to increase stability is to increase trunk tilt (Attwells, Birrell, Hooper, & Mansfield, 2006; Devroey, Jonkers, Becker, Lenaerts, & Spaepen, 2007; Hong & Brueggemann, 2000; Hong & Cheung, 2003; Jorge et al., 2018; Safikhani, Kamalden, Amri, & Megat Ahmad, 2012; Singh & Koh, 2009). Under each imitated gait pattern the participant experienced increased trunk tilt when load was added to the backpack. This adaptation aids in altering the location of the body center of mass in order to provide balance and maintain forward progression of gait (Saha, Gard, & Fatone, 2008). Mean trunk tilt increased in all gait types under load with the minimum observed in typical gait pattern with an increase of

8.4°. For pathological gait patterns, mean trunk tilt increased under load by 10.1° in toe walking, 8.8° in crouch gait, and the maximum increase of 10.3° observed in jump gait. The increase in mean trunk tilt are in agreement with previous literature on backpack load which found that with increased loads up to 20% body weight, an increase in trunk tilt is observed (Attwells et al., 2006; Brackley & Stevenson, 2004; Hong & Brueggemann, 2000; Hong & Cheung, 2003; Kistner et al., 2013; Li & Hong, 2004; Singh & Koh, 2009).

Mean pelvic tilt is observed in typical unloaded gait at 8.7°, just under the 10° of anterior pelvic tilt considered to be the amount typically observed in a normal population (Perry & Burnfield, 2010). Mean pelvic tilt under load in typical gait yielded an increase of 2.5°. Toe walking under load increased 4.5° while loaded crouch gait increased by 1.4° and loaded jump gait increased by 4.2°. Findings are consistent with previous research displaying an increase in pelvic tilt under load (Smith et al., 2006). An increase in pelvic tilt is also observed more prominently in unilateral backpack carriage, with both unloaded and loaded sides displaying a significant increase from the norm value (Ozgul et al., 2012). These findings help support the notion that the body works to adapt for optimal center of gravity.

Mean trunk obliquity observed under load resulted in the smallest change out of the three kinematic variables. For typical loaded gait, trunk obliquity decreased by 1°, loaded toe walking decreased by 0.4°, loaded crouch decreased by 0.9°. Loaded jump gait was the only gait type which observed an increase in trunk obliquity by 1.1°. Trunk obliquity is observed prominently in unilateral backpack carriage (Drzał-Grabiec, Snela, Rachwał, Podgórska, & Rykała, 2015) and with minimal to no change in standing posture similar (Al-Khabbaz, Shimada, & Hasegawa, 2008) similar to the current case study observed during level walking.

In order to add stability in gait, it is well documented that double support time increases under load while single support time decreases (Ahmad & Barbosa, 2019; Connolly et al., 2008; Hong & Brueggemann, 2000; Singh & Koh, 2009). All loaded imitation gait types, toe walk, crouch, and jump resulted in an increase in double support time, and a decrease in single support time as compared with their unloaded counterparts. This finding is consistent with the literature on typical loaded gait (Connolly et al., 2008; Hong & Brueggemann, 2000; Hong & Li, 2001; Kim & Son, 2014; Martin & Nelson, 1986; Singh & Koh, 2009). The largest change was observed in jump gait with a 38.22 percent difference from unloaded to loaded condition. Results align with a comparison of children with diplegic cerebral palsy to normal developing counterparts (Kim & Son, 2014), however, step widths were also measured in this study aiding in further elaborate the adaptation for additional dynamic control.

In addition, the current case study shows variability in step length throughout all conditions of gait. These variances were minor in typical, toe walking, and crouch gait with less than two percent difference, while a 12.24 percent difference is observed on left side jump gait and six percent difference on the right side for jump gait. Differences in step length are documented in the literature as consistent with cerebral palsy gait as a means to stabilize disturbances in the sagittal plane related to instability (Kurz et al., 2012).

The altered center of gravity that comes as a result of pathology or as a result of applying an external load can have marked effects on the kinematics of gait including the trunk and pelvis. A normal gait needs following components, stability of the lower limb joints, clearance of the ground by the foot, adequate positioning of the foot, and adequate step length during walking (Gage, 1991). The kinematic alterations observed at the trunk and pelvis can leave these components lacking, which is likely why the overlap of these variables are observed in both pathological gait and loaded gait. In pathological gait, ankle range of motion is altered plantarflexion and dorsiflexion (Fig1.) (Miller, 2018) with decreased knee and hip extension observed in crouch and jump gait.

Information gained from this case study will add to the existing literature and open a door to further explore loaded patterns of pathological gait such as those exhibited in cerebral palsy. A recent introduction of simulation gait studies has opened another possibility for future research which has the ability to explore computer simulations where subject-specific information can be used to form the basis for the research and load can be applied virtually. In recent reviews, it is acknowledged that the existence of such technology provides a wealth of opportunity in the field of biomechanics (Pitto et al., 2019). A universal platform and integration of available models to create a user-friendly program for clinicians is yet to be seen, however, by gaining knowledge of how parts of how the human body work, and how the human body is impacted by external events, such as load, the computer simulations created are able to investigate how each part interacts with one another (Viceconti, Hunter, & Hose, 2015)

Advancements in this technology will have to occur in order for the benefits to be seen in the clinical world. Virtual programs have been able to complete surgeries to find out which surgery would provide the most benefit, and they are also able to take into account neurological effects such as spasticity and use electromyographic data which the current study does not provide (Pitto et al., 2019; Saxby et al., 2020). In the future as ease and accessibility to computer simulations becomes more readily available this will open up many doors for more research on populations exhibiting CP gait.

Limitations

The first limitation is that the current study used one participant as a case study. Future research should use multiple participants to allow for comparison of means between conditions. The study was also conducted on an able-bodied person free of disease, where a true population which exhibits such gait types as toe walking, crouch, and jump gait, may have neurological implications that alter gait in addition to spasticity, or clonus, which a typically developing person cannot replicate (Romkes & Brunner, 2007). Within the current study the KAD was placed on the post-surgical brace which could impact knee joint calculations by increasing the measured width of the knee, used to calculate the knee joint center (Schwartz, Trost, & Wervey, 2004). Marker placement error and tester error are also prevalent in gait analysis pelvic obliquity and rotation inter- therapist standard error of 1.5° and 1.2° respectively, with pelvic tilt observing a larger standard error of 2.8° (Schwartz et al., 2004). As the source of the imitation of pathological gait was aided primarily from the post-surgical brace, ankle range of motion was not controlled for. Ankle range of motion is commonly affected in the aforementioned gait patterns therefore this should be noted as consideration for future studies to consider (Miller, 2018). The format of advancing through the walking trials was set up for convenience of adjusting the brace rather than an experimental randomization. This could have led to an improper learning effect on the participant. Future studies may want to include electromyographic testing (EMG) to capture muscle timing in imitated gait studies to further capture any compensatory muscle actions that may contribute to changes in gait under load.

Conclusion

In general, trunk tilt and pelvic tilt were exaggerated under all loaded gait types while trunk obliquity remained relatively unchanged. Walking velocity decreased, double support time increased, and single support time decreased under loaded imitation of pathological gait. The findings of this case study extend on previous research that finds that children exhibiting CP gait patterns experience adaptations to their gait in order to provide stability where it has been compromised. Further research as to how load affects different gait types should be considered.

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