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Gait adaptation during walking on an inclined pathway following spinal cord injury

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ABSTRACT

Background: Individuals with incomplete spinal cord injury need to be assessed in different environments. The objective of this study was to compare lower-limb power generation in subjects with spinal cord injury and healthy subjects while walking on an inclined pathway.
Methods: Eleven subjects with spinal cord injury and eleven healthy subjects walked on an inclined pathway at their natural gait speed and at slow gait speed (healthy subjects only). Ground reaction forces were recorded by force plates embedded in the inclined pathway and a 3-D motion analysis system recorded lower-limb motions. Data analysis included gait cycle parameters and joint peak powers. Differences were identified by student t-tests.
Findings: Gait cycle parameters were lower in spinal cord injury subjects compared to healthy subjects at natural speed but similar at slow gait speed. Subjects with spinal cord injury presented lower power at the ankle, knee and hip compared to healthy subjects at natural gait speed while only the power generation at push-off remained lower when the two groups performed at similar speed.
Interpretation: The most important differences are associated with the fact that individuals with spinal cord injury walk at a slower speed, except for the ankle power generation. This study demonstrated that, even with a good motor recovery, distal deficits remain and may limit the ability to adapt to uphill and downhill walking. Inclined pathways are indicated to train patients with spinal cord injury. Clinicians should focus on the speed of uphill and downhill walking and on the use of plantar flexors.

1. Introduction

Recent medical progress has allowed an increase in the survival and functional independence of people following a spinal cord injury (SCI) (Whiteneck et al., 1992). Recovering independent walk is one of the main goals of individuals with SCI, especially in people with an incomplete lesion (Scivoletto and Di Donna, 2009). About 80 to 100% of AIS D individuals will recover the ability to walk one year post injury (Lemay and Nadeau, 2010). A person is classified as AIS D if the majority of muscles below the lesion have a motor score $\geq 3/5$ according to the American Spinal Injury Association (ASIA) Scale (Scivoletto and Di Donna, 2009). A score $\geq 3/5$ indicates that the muscle has the capacity to counteract gravity. The cause and severity of the SCI will have a major influence on the rehabilitation and the capacity to walk (Noonan et al., 2012). Despite a functional recovery of walk, many limitations such as a decrease in gait speed and endurance may remain following rehabilitation (Kim et al., 2004).

Walking is a complex task that requires sufficient muscle strength, balance and coordination (Barbeau et al., 2006). For people with SCI, the strength of the leg muscles, particularly knee extensors and hip muscles, seems to be one of the principal factors that can predict their capacity to recover a functional walk (Barbeau et al., 2006; Kim et al., 2004). Meanwhile, other clinical factors such as spasticity, posture, co-contractions and loss of proprioception can limit the ability to walk (Barbeau et al., 2006; Brotherton et al., 2007; Leroux et al., 1999; Scivoletto et al., 2008). In addition to a decrease in step length and an increase in double time support in comparison to healthy individuals (Barbeau et al., 2006), subjects with SCI who are able to walk also present an increased knee flexion and an abnormal knee–hip coordination compared to healthy subjects (Leroux et al., 1999). Changes in muscular activation may limit their capacity to adapt their gait in different environments (Leroux et al., 1999). Moreover, the use of walking aids is frequent in this population to assist with negotiation of the environment. However, it also may increase energy expenditure and alter posture (Leroux et al., 2006).

Walking on an inclined pathway requires changes in motor strategies to adapt to the ramp (Lay et al., 2006). During uphill walking, healthy subjects reduce their cadence (Prentice et al., 2004) and increase their step length (Kawamura et al., 1991; Leroux et al., 2002). There is also an increase in knee flexion at heel strike and an increased

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leg extension during the stance phase (Lay et al., 2006) along with an increase in propulsion (Lay et al., 2006; Leroux et al., 2002) and in hip extensor and plantar flexor moments (Lay et al., 2007). During downhill walking, healthy subjects decrease their step length (Kuster et al., 1995; Leroux et al., 2002) and increase their cadence (Kawamura et al., 1991; Kuster et al., 1995; Lay et al., 2006). Healthy subjects also show an increase in their knee flexion during the stance phase (Lay et al., 2006; Leroux et al., 2002), knee extensors and dorsiflexor activity (Kuster et al., 1995; Lay et al., 2007) and breaking force (Lay et al., 2006, 2007).

Few studies have quantified the adaptation of subjects with SCI walking on an inclined pathway. Their capacity to adapt to inclined surfaces seems to be correlated with their gait speed during level walking (Leroux et al., 1999, 2006). During uphill walking, subjects with SCI present an increase in hip and trunk flexion and a weak push-off at the end of the stance phase (Leroux et al., 1999). This constant trunk flexion position minimizes the gravity effect on the knee extensors during uphill walking but might reduce the capacity to adapt to downhill walking (Leroux et al., 2006). In fact, a normal adaptation is to present a backward tilt of the trunk as the descending slope increases (Leroux et al., 2002). With regard to these results, this population seems to present impaired adaptations to inclined walking which can lead to a loss of balance and an inefficient gait pattern characterized by a decreased walking speed.

Authors agree that more studies are necessary to increase our understanding of the walking adaptation of people with SCI in more challenging environments to optimize their rehabilitation. Jayaraman et al. (2006) demonstrated that individuals with incomplete SCI presented deficits in generating peak isometric torque in the knee extensor and plantar flexor muscle groups during a voluntary contraction. Considering the role of the ankle in propulsion during walking, the difficulty in generating an adequate push-off could have a functional impact on their gait abilities. In addition, individuals with SCI generally present a decrease in angular excursion, reducing their capacity to produce high angular velocities and, consequently, decreasing lower-limb power values (Barbeau et al., 2006). Thus, because of the changes in kinetics and the frequent occurrence of uphill and downhill walking in daily living, it is necessary to determine how individuals with incomplete SCI performed in comparison to healthy subjects when they negotiate an inclined pathway. In addition, Sheehan and Gottschall (2012) demonstrated that slope and stair walking presented a greater fall risk than level walking in healthy individuals. Their results also showed a greater fall risk in slope walking compared to stair walking at similar angles. A greater fall risk during slope walking combined with difficulties producing lower-limb joint powers and impairments in trunk control in individuals with incomplete SCI may limit their capacity to walk on an inclined pathway and increase the risk of injury. Therefore, the main objective of this study was to evaluate the impact of the SCI on the ability to walk uphill and downhill by comparing lower-limb gait cycle parameters and power generation and absorption between people with SCI and healthy subjects while walking on an inclined pathway. Specific objectives are to compare the values of the two groups of subjects 1) at natural gait speed (NGS) and 2) at matched speed; slow gait speed (SGS) for the healthy subjects and NGS for participants with SCI. We hypothesized that subjects with a SCI would present similar results to healthy subjects when the two groups walk at comparable speed.

2. Methods

2.1. Participants and clinical assessment

A convenience sample of patients was recruited from the SCI rehabilitation unit of the Institut de readaptation Gingras-Lindsay de Montreal (IRGLM). Subjects were included in the study if they were able to walk on the inclined pathway (uphill and downhill) without walking aids, holding the rails or human assistance. Subjects were excluded if they had another disease in addition to the SCI (including a lower-limb or head trauma) or an insufficient tolerance level (<120 min with rest). Ethics approval was obtained from the Research Ethics Committee of the Center for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR 395-1108). Written consent was obtained after participants had read and understood the information about the research.

Table 1
Clinical characteristics.

Clinical characteristics	Healthy participants (n = 11)		Participants with SCI (n = 11)	
	Mean	SD	Mean	SD
Age (yr)	50	14	50	15
Height (m)	1.68	0.10	1.71	0.08
Weight (kg)	68.6	12.1	77.4	15.3
BMI (kg/m^2)	24.1	2.3	26.2	3.59
Natural gait speed (m/s)				
Level walking	1.16	0.21	0.98	0.27
Uphill walking	1.21	0.25	0.84	0.21
Downhill walking	1.22	0.19	0.77	0.29
Slow gait speed (m/s)				
Level walking	0.82	0.13		
Uphill walking	0.92	0.19		
Downhill walking	0.95	0.16		

A physical therapist evaluated every participant to obtain clinical characteristics. Clinical gait speeds (level, uphill and downhill walking) were measured over known distances: 3 m for level ground and 3.65 m for uphill and downhill walking (Table 1). Lower-limb strength was obtained using the Lower Extremity Motor Score (LEMS) of the ASIA Scale (maximal score of 25 by extremity) and balance was evaluated using the Berg Balance Scale (BBS, a maximal score of 56 indicated no balance deficit). According to a study, the BBS is a valid scale for evaluating balance in this population when combined with gait speed information (Lemay and Nadeau, 2010).

2.2. Experimentation

Participants were invited to the Pathokinesiology laboratory, located on the 4th floor at IRGLM, for a 3-hour session and were asked to walk on the inclined pathway (uphill and downhill) at natural gait speed. Healthy subjects repeated the same tasks at slow gait speed (80% of natural gait speed). Between each trial, participants had the chance to take a rest. Participants executed a minimum of five trials for each condition, excluding the familiarization. The inclined pathway used in this study was 3.65 m long by 1.20 m wide and had a ramp of 8.5° (15%) (Fig. 1). A 1-m-long platform is annexed at the end of the pathway and handrails are placed on each side of the ramp for safety. Two AMTI$^{®}$ force plates are embedded in the middle of the inclined pathway to record forces and moments in three directions (x, y and z). Data were collected at a 600 Hz sampling frequency. There is no contact between the force plates and the inclined pathway so as to limit errors due to vibrations. These force plates have a ramp of 8.5° and were fixed on the ground before installing the inclined pathway. Four motion analysis cameras (60 Hz; Optotrak model 3020; NDI Technology Inc., Waterloo, Ontario, Canada) recorded the spatial position of 36 skin-fixed infrared light emitting diodes (LEDs) placed on the lower limbs, trunk and upper limbs (at least three LEDs on each major segment). A six-marker probe was used to define 26 bony landmarks to locate joint articulations relative to their segment. Kinetic and kinematic data were synced. An inverse dynamics analysis was performed using a link segment model, as defined by Winter (1991).