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Sit-to-stand biomechanics of individuals with multiple sclerosis

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ABSTRACT

Background: It is unclear how people with multiple sclerosis, who often have compromised strength and balance, compare to healthy controls during sit-to-stand movements. The purpose of this study was to compare sit-to-stand biomechanics among three groups: people with multiple sclerosis who exhibit leg weakness, people with multiple sclerosis who have comparable strength to controls, and healthy controls.

Methods: Twenty-one individuals with multiple sclerosis ($n = 10$ exhibiting leg weakness: $n = 11$ exhibiting comparable strength to controls), and 12 controls performed five sit-to-stand trials while kinematic data and ground reaction forces were captured. ANOVAs followed by Tukey's post-hoc tests ($\alpha = 0.05$) were used to determine group and limb differences for leg strength, movement time, and sagittal-plane joint kinematics and kinetics.

Findings: Persons with multiple sclerosis exhibiting leg weakness displayed decreased leg strength, greater trunk flexion, faster trunk flexion velocity and decreased knee extensor power compared to the other two groups ($p < 0.05$; $d \geq 0.87$), and slower rise times compared to controls($p < 0.03$; $d \geq 1.17$). No differences were found between controls and the multiple sclerosis-comparable strength group. Across all 3 groups, leg strength was moderately correlated with trunk kinematics and knee extensor velocities, moments and powers of the sit-to-stand ($p \leq 0.05$).

Interpretation: Participants with multiple sclerosis exhibiting leg weakness took longer to stand and appeared to use a trunk-flexion movement strategy when performing the sit-to-stand. The majority of group differences appear to be a result of leg extension weakness. Treatment that includes leg strengthening may be necessary to improve sit-to-stand performance for people with multiple sclerosis.

1. Introduction

Multiple sclerosis (MS) is a progressive, degenerative disease of the central nervous system (Frohman et al., 2006). Common symptoms associated with MS include muscle weakness, fatigue, impaired balance, and an overall reduction of physical activity (Motl, 2014; Ponichtera et al., 1992; Van Emmerik et al., 2010). As these symptoms worsen, the ability to perform functional activities, such as standing up from a seated position, can become increasingly difficult (Wetzel et al., 2010). The sit-to-stand (STS) is a precursor to all other movements and fundamental to maintaining functional independence (Kralj et al., 1990). A decreased ability to perform STS movements is likely to propagate the downward spiral of increased disability and decreased functional ability for people with MS. Consequently a premature loss of independence may occur (White and Dressendorfer, 2004).

The most influential variable affecting an individual's ability to perform the STS is leg extension strength (Bernardi et al., 2004; Van der Heijden et al., 2009), which is a major obstacle for individuals with MS who historically exhibit leg extensor weakness (Lambert et al., 2001). It is currently unknown how muscle weakness affects STS movement mechanics for people with MS or the movement strategies people with MS use to perform the STS. Furthermore, prior investigations reporting leg strength deficits and slower movement times during the timed up and go and repeated STS movements have typically grouped all MS participants together regardless of leg strength (Allali et al., 2012; Dalgas et al., 2009). Not all persons with MS have leg strength deficits, and those who do not yet display leg weakness may not display the same STS movement mechanics or utilize the same movement strategies as persons with MS who have leg strength deficits.

It is likely that persons with MS, who have leg strength deficits, display similar STS mechanics to other clinical populations with leg weakness. Both the elderly and those with Parkinson's disease have been reported to us a 'trunk-flexion' movement strategy when performing an STS. (Inkster et al., 2003; Papa and Cappozzo, 2000). The trunk-flexion strategy is characterized by excessive trunk flexion, trunk flexion velocity and a non-overlapping sequence of movements: trunk flexion, knee extension,

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and trunk extension (Doorenbosch et al., 1994). Researchers suggest that using the trunk-flexion strategy can reduce knee extensor moment and increase stability (Doorenbosch et al., 1994; Inkster and Eng, 2004). By identifying differences in STS movement mechanics and strategies in persons with MS, targeted rehabilitation programs could be initiated to assist with and potentially improve the STS movement.

The purpose of this study was to compare STS biomechanics among three different groups: people with MS who exhibit leg extensor weakness (MS-LW), people with MS who have comparable strength (MS-CS) to non-MS controls, and healthy controls who do not have MS (CON). We hypothesized that, compared to the MS-CS and CON groups, the MS-LW group would have the slowest movement times; and they would use the trunk-flexion strategy, that is, exhibit increased trunk flexion and trunk flexion velocity, a more anterior-positioned COM at seat off, reduced knee extensor moments and greater maximum hip extensor moments. We hypothesized no differences between the MS-CS and CON groups for any of the outcome variables.

2. Methods

2.1. Participants

All participants provided written informed consent as approved by the local institutional human subjects review board. A medical history questionnaire was completed by each participant to determine whether inclusion criteria were met. The criteria for individuals with MS included having physician approval, relapsing–remitting MS that was physician diagnosed, and an expanded disability status score (EDSS) of <6.5 (White et al., 2004). It was acceptable for participants to use MS-modifying drugs interferon beta 1α and 1β. Excluded was any potential participant who was pregnant; had orthopedic limitations of the lower extremity or trunk that prohibited STS; or had used prednisone or other steroids for an MS flare-up during the previous three months. All control participants were apparently healthy, with no known visual, vestibular or neurological disorders.

Twenty-one individuals with MS and 12 non-MS controls (CON; $n = 2$ male, 10 female) matched for age (±2 yr), height (±0.1 m), and mass (±5 kg), who were recruited from the surrounding communities, MS support groups, and neurology clinics participated in this study. Participants with MS were divided into two groups based on their 1 repetition max (1RM) on a bilateral leg press test. Persons with MS whose 1RM leg press, adjusted for weight, was less than the lowest 1RM within the CON group were placed in the MS leg extensor weakness group (MS-LW; $n = 1$ male, 9 female). All remaining persons with MS who participated in the study were placed in the MS comparable leg extensor strength group (MS-CS; $n = 2$ male, 9 female). Descriptive statistics of participants for each group are found in Table 1.

2.2. Instrumentation

To determine lower extremity muscle strength, a Cybex® leg press machine (Cybex International Inc., Medway, MA, USA) was used. The bilateral leg press task was chosen as it closely mimics the bilateral leg extension used to rise during the STS movement.

For the STS task, sagittal plane kinematic data of the trunk and lower extremities were collected (100 Hz) using an electromagnetic motion tracking system (Flock of Birds, Ascension Technologies, Burlington, VT, USA) and *Motion Monitor*™ software (v.7, Innovative Sports Training, Chicago, IL, USA). A total of seven, six-degrees of freedom position sensors were secured to each subject. A sensor was placed on the sternum, sacrum and each foot, shank, and upper leg (Brown et al., 2008). A temporary sensor, attached to a plastic stylus, was used to digitize anatomical joint locations within the electromagnetic field. With the participant in a neutral stance, the end of the stylus was placed on anatomical landmarks, as per standard protocol, while the extended range transmitter collected sensor positions (Brown et al., 2008). Vertical and anteroposterior ground reaction force signals were collected (1000 Hz) using two non-conducting Bertec Force Plates (Model #4060-NC, Bertec Corporation, Columbus, OH, USA).

Table 1
Participant demographics mean (SD).

Group	n	Age (years)	Height (cm)	Mass (kg)	BMI	EDSS
MS-LW	10	49.2(10.3)	166.9(7.5)	82.2(15.5)	29.5(4.7)	4.3(1.4)
MS-CS	11	39.8(11.9)	165.7(6.7)	76.3(23.4)	27.5(6.9)	1.6(2.2)[a]
CON	12	42.8(11.8)	165.5(7.8)	74.2(19.5)	26.8(5.0)	na

[a] Significantly different from the MS-LW ($p < 0.001$).

2.3. Data collection

Data were collected during three separate data collection sessions with 48 h between each session. During the first two sessions bi-lateral lower extremity strength was tested using a one-repetition maximum (1RM) protocol (Barnard et al., 1999). The participant performed a light warm up on the Cybex® leg press machine. After 3–5 min of rest, weight was added to the Cybex® leg press and the participant performed the leg extension exercise. If the participant was able to perform the leg extension through the full range of motion, the trial was considered successful and additional resistance was added. Three to five minutes of rest was given between each attempt. This process was repeated until the participant was unable to perform the leg extension after two attempts. The last weight the participant was able to lift successfully was considered the 1RM for that session.

During a third session participants performed the STS task. Seat height, foot position, and hand use were controlled. Participants started the task seated on an adjustable-height chair so the hip, knee and ankle joint angles for both legs were at approximately 90°. Each foot was positioned on a separate force plate and aligned parallel to the sagittal plane. Participants were instructed to fold their arms across the chest during the entire movement (Camargos et al., 2009). At a self-selected speed and without shifting the feet, the participant rose from the chair to a fully erect posture. A minimum of two practice trials were performed prior to collecting any data. Data were captured during five successful trials with 2–3 m rest between each trial. Unsuccessful trials where participants shifted the feet or were unable to stand up completely were repeated.

2.4. Data processing

Strength measures were scaled to body weight. The higher 1RM value of the two visits was used to divide the participants with MS into two groups and subsequently used to compare the overall lower extremity strength among all three groups.

For the STS data, the start of the STS movement was defined as the instant at which the horizontal COM velocity was $>0 \text{ m s}^{-1}$ and continued to increase. The end of the STS movement was defined as the instant that both maximum trunk extension and knee extension had been reached. The seatoff event, the instant when the value of the anterior ground reaction force attained its greatest value (Kralj et al., 1990), was used to divide the STS movement into two phases: pre- and post-seat off. Sagittal plane kinematic and kinetic quantities were calculated using *The Motion Monitor*™ software (v.7). The spatial locations of the Flock of Birds sensors were reconstructed. Following International Society of Biomechanics guidelines, Euler angles (XY′Z″) were calculated at the hip and knee joints and adjusted relative to natural standing with sagittal plane motion occurring around the first rotation (X) (Wu and Cavanagh, 1995). Trunk flexion was calculated in the global coordinate system relative to vertical.

In addition to segment and joint angles, anteroposterior position of the COM of the entire body was calculated. Kinematic data were filtered