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Kinematic and electromyographic analyses of normal and device-assisted sit-to-stand transfers

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ABSTRACT

Mechanical sit-to-stand devices assist patient transfers and help protect against work-related injuries in rehabilitation environments. However, observational differences between patient's movements within devices compared to normal sit-to-stand transfers deter clinician use. This study compared kinematics and muscle demands during sit-to-stand transfers with no device (ND), and device-assisted during which participants exerted no effort (DA-NE) and best effort (DA-BE). Coefficient of multiple correlations (CMCs) compared kinematic profiles during each device-assisted condition to ND. Compared to DA-NE, CMCs were higher during DA-BE at the hip, knee, and ankle. However, DA-BE values were lower than DA-NE at the trunk and pelvis due to the device's mechanical constraints. In general, all joints' final DA-NE postures were more flexed than other conditions. Electromyographic was significantly lower during DA-NE compared to ND for all muscles except lateral hamstring, and during DA-BE compared to ND for gluteus maximus, gastrocnemius, and soleus. Verbal encouragement (DA-BE) significantly increased medial hamstring, vastus lateralis, gastrocnemius, soleus and tibialis anterior activation compared to DA-NE. In conclusion, device-assisted sit-to-stand movements differed from normal sit-to-stand patterns. Verbally encouraging best effort during device-assisted transfers elevated select lower extremity muscle activation and led to greater similarity in hip, knee and ankle movement profiles. However, trunk and pelvis profiles declined.

1. Introduction

Workplace injuries are prevalent in healthcare [1–10]. Among nursing home employees, incidence rates for back injuries resulting in lost work days are more than twice construction workers' rates and over three times agricultural workers' rates [1–6]. A significant number of clinicians' injuries result from lifting and transferring patients [11]. Physical therapists performing 6–10 patient transfers a day are 2.4 times more likely to experience low back injuries than therapists not performing transfers [12].

The nursing profession's implementation of safe patient handling and movement policies [13] has dramatically reduced work-related injuries [14], chronic pain (23%) [15], medical expenses (74%), worker compensation payments (50%), and estimated restricted duty costs (95%) [16]. One tool emerging from these initiatives is the battery-powered sit-to-stand transfer device. It safely lifts and lowers patients between seated and standing positions, while reducing the risk of caregiver injury [17,18].

Given notable reductions in injuries that have arisen from implementing safe lifting policies in nursing, it is reasonable to expect that therapists would readily incorporate lifting equipment into their routines to reduce injuries. However, therapists have been reluctant to adopt device usage due to concerns regarding therapeutic value [19]. Movement patterns displayed by patients when performing device-assisted transfers observationally differ from normal sit-to-stand transfers. Additionally, traditional approaches to using automated devices often do not encourage patients to try to stand-up, thus may discourage active muscle engagement compared to clinician-assisted transfers. Clinicians' concerns regarding mechanical sit-to-stand devices arise in part from current practice paradigms that emphasize intensive, task-specific training for promoting recovery of function and cortical reorganization following neurologic injury [20,21].

Given the importance of task specificity to rehabilitation, this study's primary aim was to explore whether kinematic and electromyographic patterns during device-assisted sit-to-stand transfers were similar to unassisted transfers. Individuals without

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known pathology were specifically recruited to isolate the effects of the device's mechanical design from the confounding influence of weakness, balance impairments, and movement control deficits on transfers. Participants were assessed while exerting no purposeful effort to simulate traditional device-assisted sit-to-stand transfers performed by patients. Participants also were assessed while attempting to offer their best effort to stand within the device to explore the mechanical constraints imposed by the device. It was hypothesized that compared to sit-to-stand transfers without a device, during device-assisted conditions forward trunk lean would be restricted due to the device's mechanical constraints. Additionally, it was hypothesized that the ankle would show minimal motion during device-assisted sit-to-stands because ankle stabilizing mechanisms would constrain dorsiflexion. Finally, it was hypothesized that muscle activity would be greater in key lower extremity extensors when participants were encouraged to use their legs to help stand within the device.

2. Methods

2.1. Participants

Ten adults (5 males), free from musculoskeletal and neurological impairment, were recruited from the local community [mean (SD) age: 21.0 (2.4) years; body mass: 71.9 kg (10.7); height: 178.2 cm (12.2)].

2.2. Instrumentation

The Qualisys Motion Analysis System and Qualisys Track Manager software (Gothenburg, Sweden) defined three-dimensional motion (12 Oqus Series-3 cameras, sampling rate 120 Hz). The MA-300-10 EMG system and MA-411 surface electrodes (Motion Lab Systems, Inc., Baton Rouge, LA) recorded muscle activity. Signals were low-pass filtered (500 Hz) and digitally recorded (1200 Hz). Visual 3D software (C-Motion, Inc., Germantown, MD) performed signal processing.

A Vera-lift sit-to-stand device (Model V350, Vancare Inc., Aurora, NE) was used (Fig. 1). It included a rotation arm (54 cm long) capable of elevating a body sling from 111 cm to 173 cm above the floor and a foot platform (43 cm by 32 cm) located ~11 cm above floor level and tilted ~8° upward (heel to toe). Velcro strapping secured participants' lower legs to dense foam (~46 cm by 16 cm) to prevent knee collapse during transfers.

2.3. Procedure

Testing was performed in Madonna Rehabilitation Hospital's (MRH's) Movement and Neurosciences Center after participants signed an informed consent approved by MRH's Institutional Review Board.

EMG electrodes were secured over muscle bellies of the right limb's gluteus maximus, gluteus medius, vastus lateralis, medial hamstring, lateral hamstring, tibialis anterior, medial gastrocnemius and soleus using standard techniques [22,23]. Inspection of real-time EMG signals during specific resisted movements validated electrode placement. Following practice, a 5-s EMG signal was recorded during maximum isometric manual muscle testing of each muscle using standard tests [24]. Then a 5-s resting EMG trial was recorded.

Reflective markers were placed bilaterally over the acromion processes, iliac crests, posterior superior iliac spines (PSIS), anterior superior iliac spines, and the right lower extremity's greater trochanter, medial and lateral femoral condyles, bilateral medial and lateral malleoli, posterior heels, medial first metatarsal head (MTH), between distal second and third MTHs, distal lateral fifth MTH, and midfoot's lateral border [25]. Twelve tracking marker clusters were secured on the trunk, thighs and shanks [26]. A static calibration trial was recorded to define the 16-segment model.

Kinematics and EMG were recorded simultaneously while participants performed the following (three times, random order):

1. No device (ND): sit-to-stand without device (participants' self-selected seating posture and foot stance). Instructed, "Beginning in a seated position, please stand up at your normal comfortable speed."
2. Device-assisted-best effort (DA-BE): instructed, "We would like you to stand up with the device. Use your legs to stand up as best you can within the device. Please do not use your arms to lift your body. We will use a remote control to control the device as it lifts your body."
3. Device-assisted-no effort (DA-NE): instructed, "We would like you to let the device lift your entire body weight. Do not assist the device. Lean back into the sling so it can support your whole body weight. We will use a remote control to control the device as it lifts your body."

Participants started seated on a backless and armless chair (18 in. height). In no device trials, participants moved at a self-selected speed. During device-assisted trials, the device's default speed was used.

2.4. Data analysis

2.4.1. Onset and cessation

Left PSIS marker data defined and normalized movement cycles. Onset, or zero percent movement cycle (0% MC), was defined as the frame at which the PSIS marker's location increased vertically more than three standard deviations from the first 100 frames' average prior to motion initiation. Cessation (100% MC) was defined as the frame at which the marker reached maximum anterior position.

2.4.2. Kinematics

Visual 3D was used to produce a 3-dimensional trajectory for each marker and for filtering (6-Hz Butterworth low-pass digital). The position and orientation of trunk, pelvis, thigh, shank and foot segments were obtained and lower extremity joint angles calculated for each %MC. Sagittal plane trunk and pelvis orientations were expressed relative to vertical while hip, knee and ankle angles were generated by their relative segments. Separate ensemble averaged joint angle plots were created for each participant and condition, and start, end and peak joint angles were identified. Three group ensemble averaged profiles (ND, DA-BE and DA-NE) were created for each joint angle by combining all participants' data.

2.4.3. Electromyography

One participant's gluteus maximus data were excluded from analysis due to electrode failure. After adjusting for DC bias and baseline noise, EMG data were digitally filtered (60 Hz notch, 10 Hz high-pass and 350 Hz low-pass Butterworth), full-wave rectified, and integrated over 0.01 s intervals. EMG timing, duration, and amplitude were calculated using Visual 3D software and intensities (peak, mean) were normalized and reported as a percentage of the maximal isometric manual muscle test (%MMT). Onsets and cessations were determined for all EMG envelopes exceeding 5% MMT amplitude [27,28]. EMG envelopes separated by short gaps (<50 ms) were combined into larger packets for duration calculations (expressed as %MC). A time-normalized mean profile for each participant and muscle was created for each condition.

2.5. Statistical analysis

Separate one-way analyses of variance with repeated measures identified significant differences in kinematic and EMG variables between ND, DA-BE and DA-NE. When normality assumptions were violated, Friedman's ANOVA on ranks identified significant differences. Bonferroni adjustments accounted for multiple comparisons within kinematic ($p < 0.01$) and EMG variable families ($p < 0.006$). Coefficients of multiple correlations (CMC) [29] were calculated to quantify similarity in movement patterns of DA-BE and DA-NE to ND for each joint.

3. Results

3.1. Kinematics

Compared to ND, device-assisted conditions (i.e., feet supported on platform) resulted in significantly narrower heel-to-heel (ND = 24 cm vs. DA-BE = 18 cm, DA-NE = 17 cm; $p < 0.001$) and toe-to-toe (ND = 35 cm vs. DA-BE = 26 cm, DA-NE = 27 cm; $p < 0.001$) distances.

Compared to DA-NE, CMC values were higher during DA-BE at the hip (0.87 vs. 0.77), knee (0.95 vs. 0.86), and ankle (0.69 vs. 0.58; Fig. 2). In contrast, DA-BE values were substantially lower than DA-NE at the trunk (0.49 vs. 0.56) and pelvis (0.35 vs. 0.75).

In general, the *final* DA-NE joint postures were more flexed than the other two conditions (Table 1 and Fig. 2). *Trunk* flexion was less during DA-BE compared to ND at each epoch (start, peak, end). Progressive trunk extension during DA-NE and subtle trunk flexion during DA-NE contrasted sharply with ND's characteristic flexion wave. Peak trunk flexion timing varied notably between ND (38% MC) and DA-NE (95% MC). Participants ended in significantly greater trunk flexion during DA-NE than ND, and both exceeded that recorded during DA-BE.

The *pelvis* started in significantly greater posterior tilt during both device-assisted conditions compared to ND. While peak anterior tilt did not differ significantly between DA-NE and ND, the peak's timing was notably delayed for DA-NE (99% MC) compared