2003

Comparison Between Successful and Failed Sit-to-Stand Trials of a Patient After Traumatic Brain Injury

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ABSTRACT. Zablotny CM, Nawoczenski DA, Yu B. Comparison between successful and failed sit-to-stand trials of a patient after traumatic brain injury. Arch Phys Med Rehabil 2003;84:1721-5.

Objective: To compare the peak whole-body center of mass (COM) velocities and joint angular contributions in successful and unsuccessful sit-to-stand (STS) trials in a subject with traumatic brain injury (TBI).

Design: Single-case study.

Setting: Motion research laboratory.

Participant: A 24-year-old man who was 3.5 years post-TBI.

Interventions: Not applicable.

Main Outcome Measures: Peak horizontal and vertical velocities of the whole-body COM and peak angular velocities of the ankle, knee, hip, and shoulder joints.

Results: The peak whole-body COM vertical velocity was significantly lower in the unsuccessful STS trials. Angular velocities at the hip, knee, ankle, and shoulder joints in successful trials exceeded those in unsuccessful trials ($P<.001$). The subject's peak knee extension velocity was the single major predictor of the peak whole-body COM vertical velocity ($r^2=.90$). Knee extension angular velocities greater than 3.25 radian/s were associated with successful STS trials. Knee extension angular velocities between 2.75 and 3.25 radian/s were associated with successful rising 50% of the time; the subject had no success in rising when velocities were less than 2.75radian/s.

Conclusions: For this subject, sit-back failures occurred in STS attempts characterized by peak whole-body COM vertical velocities that were lower than those generated in successful rising trials. These unsuccessful rising attempts were primarily the result of the subject's inability to generate sufficient knee extension angular velocity.

Key Words: Brain injuries; Kinematics; Rehabilitation.

THE EVERYDAY TASK of rising from a seated position to a standing position is a precursor for function in an upright posture. This transitional task of moving from sit-to-stand (STS) is routinely addressed by rehabilitation specialists working with people with a wide range of impairments that have resulted from musculoskeletal or neurologic involvement. Clinicians and their patients analyze both failed and successful STS attempts as a means of enhancing functional performance, safety, and consistency with this task.

Most of the literature about the STS movement has focused on describing successful attempts at rising by individuals without musculoskeletal or neurologic involvement.[1-12] Successful STS outcomes generally imply that a person can rise from a seated position without hesitancy or loss of balance.[13] Studies investigating the kinematic variables associated with successful STS outcomes have analyzed whole-body center of mass (COM) linear motion in the horizontal and vertical directions.[2-4,6-9,12,13] The contribution of joint angular motion to whole-body motion during STS has also been investigated.[5,6,8-12] This work has provided information about the magnitude and timing characteristics of whole-body linear velocity and momentum in able-bodied people as they transition from STS.

To date, only a few studies have analyzed failed STS attempts. Riley et al[13] described the kinematics of 2 different types of STS failures in a group of elders with various neuromuscular and musculoskeletal disorders, including some who had balance impairment resulting from vestibular hypofunction. The authors used their "target of opportunity" data to describe 2 types of STS failures: (1) the "sit-back" failure, which implies that the subject rises slightly off the chair and then sits back down, and (2) the "step" failure, which occurs when subjects are unable to stop their motion after rising and take a step to prevent a fall. Both failure modes were associated with insufficient maximum whole-body vertical momentum when compared with successfully completed STS outcomes in a control group of healthy elders. Descriptions of STS failure mechanisms such as these in other patient populations are currently not available in the literature.

Currently the STS literature also contains few studies on how individual lower-extremity joint motion may influence whole-body motion and affect the outcome of a rising attempt in individuals with neurologic or musculoskeletal involvement. This information has particular relevance to clinicians who are challenged to develop specific rehabilitative strategies that will enhance the abilities of their clients to stand. A mathematical model relating joint angular motion and whole-body STS movement was introduced by Yu et al[12] and applied to a group of unimpaired individuals. Yu determined that hip, knee, and ankle joint angular motions have varied roles in the control of the horizontal and vertical components of whole-body linear motion during STS. To date, this model has not been applied to the analysis of STS movement in individuals with neurologic involvement.

Our purpose in this single-case study was to compare the peak whole-body COM velocities and joint angular contributions in successful and failed STS trials in a subject with traumatic brain injury (TBI). Using target of opportunity data collected randomly during STS attempts may improve our understanding of the kinematic behavior that contributes to

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Presented in part at the American Physical Therapy Association National Conference, June 1999, Washington, DC.

Supported in part by the Research Designated Fund for Clinical Research, New York Chapter of the American Physical Therapy Association.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the author(s) or upon any organization with which the author(s) is/are associated.

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sit-back failures and may provide a basis from which to develop meaningful rehabilitation strategies.

METHODS

Participant

The subject was a 24-year-old man who was 3.5 years post-TBI. He was recruited from a local outpatient physical therapy clinic. He was 1.84m tall and weighed 78.92kg. He was neurologically stable and could assume a standing position without physical assistance. His cognition level was such that he could follow directions, and he displayed behaviors consistent with a level VII (Automatic and Appropriate) on the Rancho Los Amigos Levels of Cognition Scale.[14] He routinely wore bilateral ankle-foot orthoses (AFOs) for stability and balance during his upright activities.

Originally, this man was the single subject in a primary study that examined the effect of different AFO configurations on the STS transition. While collecting data for this original study, we observed that the subject was not always successful in assuming a standing position; that is, he occasionally had sit-back failures onto the seated surface. From these data, we were able to compare the subject's successful and failed STS outcomes while he was wearing bilateral custom-molded jointed polypropylene AFOs that restricted ankle plantarflexion motion beyond neutral.

This study was approved by the Review Board for Human Subjects Research at Ithaca College and the University of Rochester. Written, informed consent was obtained from the subject.

Instrumentation

We used a Panasonic 450 AGS-VHS video camcorder[a] to collect 2-dimensional coordinate data at a rate of 60 frames per second. The camera was leveled and positioned 3.8m from the subject to give a right side sagittal view. A simple closure switch was placed under his right ischial tuberosity and synchronized with a light-emitting diode that was placed in view of the camera to indicate when he lifted his buttocks from the bench seat.

Protocol

A practice session was conducted before the first testing session to familiarize the subject with the test protocol and the laboratory environment. Markers were placed over the following landmarks on the subject's right side: fifth metatarsal head, lateral malleolus, midknee joint axis, greater trochanter, lateral border of the acromion process, lateral humeral epicondyle, and the dorsal aspect of the forearm over the styloid process of the ulna. Before each trial, the subject sat on a specially designed bench whose height of 0.6m was equal to the seat height of his wheelchair. To ensure a consistent starting position, tape markers were used to outline the posterior and lateral borders of his seated base of support. Foot position relative to the bench was selected by the subject at the start of the experiment and was maintained across all testing conditions. Also, the same footwear was worn for all testing.

During the tests, the subject adopted an arm positioning and movement strategy that he routinely used in his daily STS transitions. The strategy involved placing his arms together so that his elbows were extended and his shoulders were positioned in approximately 60° of flexion. He clasped his more functional left hand around his right wrist. This arm positioning prevented his right arm from posturing in excessive shoulder abduction/extension and elbow flexion and helped him maintain a more symmetrical, extended trunk posture (fig 1). The STS trial was initiated on a verbal cue from the examiner. The subject rocked forward and backward twice before attempting to rise as he brought his trunk forward a third time. The movement was performed at a self-selected comfortable speed. Adequate rest time was given between consecutive trials.

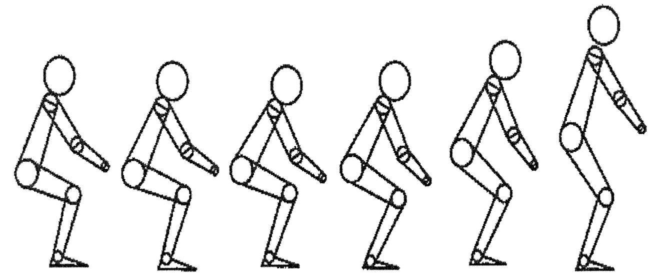

Fig 1. Representation of the subject's positioning as he transitioned from a seated position to standing.

Data were collected from all trials in the 5 testing sessions, which were held over 2 weeks. The goal was to collect data for a minimum of 3 successful STS trials in each session. A successful trial was defined as one in which the subject completed the STS transition without hesitancy or without loss of balance that resulted in his sitting back down on the bench. A failed STS trial, therefore, was defined as one in which the subject sat back down after he had lifted his buttocks off the bench.

Data Reduction and Analysis

The digitized 2-dimensional video coordinates of the landmarks from both successful and failed trials were converted to real-life 2-dimensional coordinates by using the Kinematic Analysis Software[b] computer program package. These raw landmark coordinates were filtered through a fourth-order, zero–phase shift Butterworth filter at an estimated optimum cutoff frequency of 7.41Hz.[15] The 2-dimensional coordinates of the whole-body COM were estimated with a segmentation method[16] with a 14-segment model[17] and the segment inertia parameters modified by Hinrichs.[18] Hip, knee, and ankle joint angles were calculated as described by Winter.[19] The linear velocities of the whole-body COM and joint angular velocities were estimated by using a central finite difference method. The last frame in which the horizontal velocity of the COM was 0 before it reached its peak value was considered the beginning of the STS movement. The first frame in which the vertical velocity of the COM was 0 after it reached its peak value was considered the end of the movement. Data smoothing and kinematic data reductions were conducted with the MS2DVA computer program package.[c]

Analyses were conducted on the dependent variables of peak whole-body horizontal and vertical COM velocities and individual joint angular velocities (ankle, knee, hip, shoulder). A chi-square test was used to assess for normal distribution of data from both the successful and failed trials. Assuming a normal distribution, successful and failed STS trials were compared by using a paired t test. Multiple regression analysis was conducted to express the peak horizontal and vertical velocities of the whole-body COM as functions of the peak individual joint angular velocities. A forward stepwise procedure was used to determine the best regression equations. The independent variables (ankle, knee, hip, shoulder) were initially correlated with the dependent variables, and the variable with the

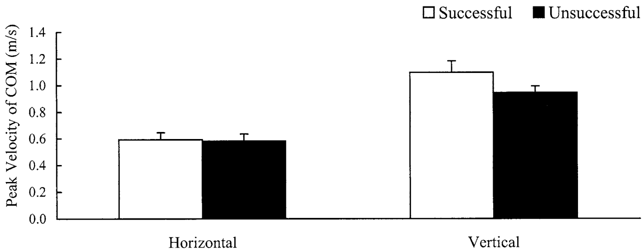

Fig 2. Comparison of peak whole-body COM horizontal and vertical velocities (mean ± standard deviation [SD]) in successful and unsuccessful STS trials.

highest correlation was entered into the equation at step 1. The best regression equations were determined with all variables that had significant contributions to the prediction of the horizontal or vertical velocity of the whole-body COM. Variables predicting less than 2% of the total variation of the horizontal or vertical velocity of the whole-body COM were not retained. A .05 type I error rate was used to indicate statistical significance. All statistical analyses were conducted using the SYSTAT statistical analysis program package.[d]

RESULTS

A total of 20 STS trials were included in the analysis. Of these, 7 (35%) resulted in the subject sitting back onto the bench before achieving a vertical position and were therefore considered sit-back failures.

The chi-square analysis found no difference in the distribution of data between successful and failed trials. When peak horizontal and vertical velocities between successful and failed outcomes were compared, significant differences were found in the peak vertical velocities ($P<.001$) (fig 2). The mean peak vertical velocity of the whole body in the successful trials (1.10±.09m/s) was greater than that in the unsuccessful trials (.95±.05m/s).

Significant differences between successful and failed trials were also found in the peak extension angular velocities of all selected joints ($P<.001$) (fig 3). Values for peak joint extension angular velocities of all selected joints were always greater in successful STS trials than in failed trials.

Multiple regression analysis of the relation between the peak vertical velocity of the whole-body COM ($V_{COM,y}$) and the peak joint extension angular velocities showed that the peak vertical velocity of the whole-body COM was a function of the

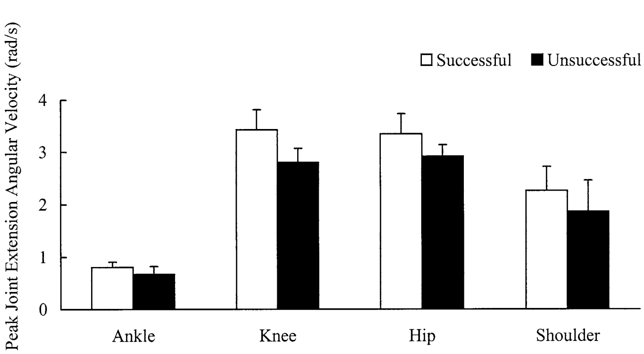

Fig 3. Comparison of peak extension angular velocities at the ankle, knee, hip, and shoulder joints in successful and unsuccessful STS trials. Values represent the mean ± SD. Significant differences were noted at each joint (*P*<.001). Abbreviation: rad, radian.

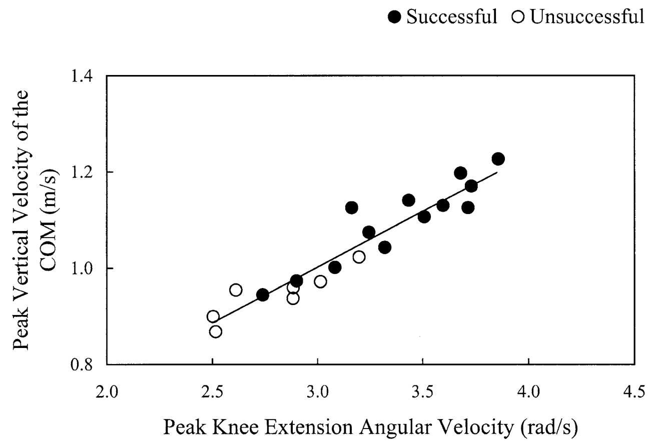

Fig 4. Regression analysis detailing the relationship between peak vertical velocity of the COM and peak knee extension angular velocity for successful and unsuccessful STS trials.

peak knee and hip joint extension angular velocities, described as

$$V_{COM,y} = .24 + .16\omega_{knee} + .09\omega_{hip},$$

where ω represents joint angular velocity ($r^2=.93$, $P=.00$).

The peak knee joint extension angular velocity predicted more than 90% of the total variation of the peak vertical velocity of the whole-body COM among all trials ($r^2_{knee}=.90$), whereas the peak hip joint extension angular velocity predicted approximately 3% of that total variation ($r^2_{hip}=.03$). The subject was always successful when his peak knee joint extension angular velocity was greater than 3.25 radian/s. All failed outcomes occurred when peak knee extension angular velocities decreased below this value (fig 4).

DISCUSSION

Previous work that analyzed STS transition in able-bodied individuals delineated specific biomechanical and motor control components critical for its success.[2-13] These components included the ability to generate adequate whole-body horizontal and vertical velocities and momenta and the ability to use motor control strategies to maintain balance as the COM is transitioned from a sitting position to a reduced base of support in the standing position. Studies that have analyzed the contribution of individual joint angular motion to whole-body motion in STS have also provided insight into why some attempts to stand are successful while others are not.[5,6,8-12] These biomechanical and motor control components will be considered in the analysis of the failed trials for the subject in this study.

The subject's movement strategy, as described by his directionally specific COM velocities, showed both similarities and differences from what has been described in the literature for able-bodied persons of similar age. Our subject generated peak horizontal velocities of the COM in successful rising attempts (.59±.05m/s) and unsuccessful attempts (.58±.05m/s) that approximated the values reported by Yu et al[12] (.61m/s) and Riley et al[7] (.57m/s). These horizontal values were consistent, regardless of the STS outcome. In contrast, the subject's COM vertical velocity values were approximately 2.5 times greater than the mean values of .35m/s and .39m/s previously reported by Yu[12] and Roebroeck et al,[8] respectively, for able-bodied subjects of similar age. This strategy of transitioning to vertical with a COM velocity that was excessive, compared with previous studies, did not always guarantee success in rising for our subject. Even with the large vertical velocity values recorded for the COM, there was still a distinction between success and failure, with these values being significantly greater in the successful rising trials ($P<.001$).

Our subject's large COM vertical velocity, when compared with that of able-bodied individuals of similar age, may have been the result of the timing in the strategy of rising that was used. Yu et al[12] reported that peak horizontal and vertical velocities of the COM occurred at 29% and 62% of the normalized STS cycle, respectively, in a group of able-bodied young adults. Our subject reached peak COM horizontal and vertical velocity at 74% and 82%, respectively, of the normalized STS cycle. This suggests that his whole-body COM transitioned from horizontal to vertical within 8% of the STS cycle time, which may have necessitated a higher value for the peak COM vertical velocity.

In their study of able-bodied adults rising at different speeds, Pai and Rogers[5] reported that the magnitude of the COM horizontal momentum was a relatively invariant feature of the STS movement, but that the COM vertical momentum increased significantly as the speed of ascent increased. Despite our subject's neurologic involvement, his data seem to reflect a similar control strategy for governing his movement. His horizontal velocities were comparable to normal values and remained relatively invariant, whereas his peak vertical velocity values varied and distinguished between successful and unsuccessful trials.

In a previous analysis of the STS movement in 10 able-bodied young adults, Yu[12] predicted that inadequate whole-body upward vertical velocity would likely result in a sit-back failure. Our data concur with this prediction from the standpoint that the mean peak vertical velocity of the whole-body COM was less in failed trials when compared with successful ones. Similarly, Riley et al[13] described the sit-back failures in their study as resulting partly from insufficient maximum whole-body vertical momentum generation, which is directly related to insufficient velocity.

We attempted to further assess reasons for success and failure by comparing lower-extremity joint angular velocities and their contribution to whole-body COM vertical velocity. Peak hip and knee extension and ankle plantarflexion angular velocities were all greater in successful STS attempts. The regression analysis showed that consistent, successful rising was largely predicted by the subject's ability to attain a peak knee joint extension angular velocity of 3.25 radian/s or greater ($r^2=.90$; see fig 4). When peak hip joint extension angular velocity was added to the model, r^2 values increased to .93. Based on the regression equation, the contributions of the knee and hip to the total COM vertical velocity were 50% and 25%, respectively. The relative contributions to whole-body vertical velocity in our subject differed slightly from those previously reported for able-bodied young adults by Yu.[12] In that study, hip and knee contributions to the maximum total upward vertical velocity of the whole body were reported as 65% and 35%, respectively. This discrepancy further supports our observation that our subject's movement pattern did, in fact, differ from that of able-bodied individuals in that knee joint motion made the primary contribution to successful attempts.

The timing of the peak extension angular velocities of the hip, knee, and ankle joints was also considered in the assessment of our subject's high vertical velocity. The timing data showed a relatively synchronous response as he stood, with the hip, knee, and ankle reaching peak velocity values at 83%±4.9%, 82%±4.4%, and 84%±4.0%, respectively, of the normalized cycle time.

One reason that has been proposed for the high knee extension angular velocities may be related to the subject's final standing position and an overall reduction in hip displacement. He never attained a fully extended hip posture, showing a final hip position of .47±.06 radian (approximately 27° of hip flexion). It is conceivable that a reduction in overall hip displacement may have resulted in the greater velocity magnitudes at the knee necessary to achieve the upright posture.

Clinical Implications

Although we recognize the limitations of this study's single-subject design and the relatively small number of trials analyzed, it does offer insight into the relation between individual joint angular velocities and their contributions to successful rising for a person with neurologic involvement. In treating patients with central nervous system pathology, rehabilitation specialists frequently focus their efforts on measuring variables such as individual joint range of motion and force control but are less likely to consider the generation of concurrent multiple joint angular velocities as they relate to a specific functional task, such as STS.[20] An increased understanding of this aspect of motor control may enable clinicians to develop treatment programs that address these issues more specifically.

The data from this study also support the concept of using a task-specific training regimen in the functional rehabilitation of a patient with neurologic involvement.[21] Our subject had antigravity, isolated knee joint extension control while sitting but was unable consistently to use this same control mechanism to meet the requirements of an STS transition. A task-specific STS training protocol tailored for him would provide practice opportunities for generating concurrent hip and knee angular velocities related to rising to a standing position. This type of training would also create a practice situation in which adjustments in postural control would be required as the subject's base of support became smaller after liftoff from the seated position.

Our subject used a rising strategy that differed somewhat from that of able-bodied, age-matched subjects, yet he was successful most of the time. This points to the need to study functional tasks such as STS in larger, more varied groups of people with neurologic diagnoses to document the range of strategies that may be adopted to successfully stand. Similarly, by expanding study protocols to include analysis of failed STS attempts in larger patient populations, clinicians will gain relevant information that can help direct their therapeutic interventions at the specific underlying impairments that most often lead to failure. An additional benefit of understanding why patients fail in their rising attempts relates to the issue of safety and risk of falls in neurologically involved people. It is not uncommon for tasks such as STS to perturb postural control enough to create a dangerous situation that results in a fall.[22]

CONCLUSION

This study analyzed successful and unsuccessful STS attempts in a single subject after TBI by comparing peak whole-body COM velocities and peak angular velocities at the ankle, knee, hip, and shoulder joints. Peak whole-body COM vertical velocity was significantly lower in the unsuccessful STS trials. Regression analysis indicated that this subject's peak knee extension velocity was the single greatest predictor of the peak whole-body COM vertical velocity and that hip extension angular velocity was the second most important contributor.

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Suppliers

a. Panasonic, One Panasonic Way, Secaucus, NJ 07094.
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c. MotionSoft; Baker Motion Control Systems Inc, 1898 Fall River Ave, Seekonk, MA 02771.
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