Whole-Body Movements During Rising to Standing from Sitting

Rising to a standing position from a sitting position is one of the most important activities of daily life. We present a total-body analysis of rising from a chair as performed by nine healthy individuals under controlled conditions. We describe four phases of this activity. Phase I is a flexion-momentum phase used to generate the initial momentum for rising. Phase II begins as the individual leaves the chair seat and ends at maximal ankle dorsiflexion. Forward momentum of the upper body is transferred to forward and upward momentum of the total body. Phase III is an extension phase during which the body rises to its full upright position. Phase IV is a stabilization phase. Kinetics and kinematics of the phases are analyzed. The phases are differentiated in terms of momentum and stability characteristics. Clinical implications of the mechanics of rising are discussed.

Key Words: Kinesiology/biomechanics, sit-to-stand analysis, Motion analysis; Movement; Sit-to-stand.

One of the most common activities of daily life is to rise to a standing position from a sitting position. We come to a standing position when we get out of bed in the morning; when we leave the breakfast table; after visiting with friends; and when we leave our seats on buses, trains, or subways. In short, we are constantly standing up from a sitting position as we carry out our daily activities. In a therapeutic setting, one of the most important tasks that we teach patients is how to rise from the sitting position.

It is necessary to establish the dynamics of functional activities, such as rising to a standing position, as carried out by healthy individuals, in order to analyze and correct abnormality in individuals who have impairments. Rising to a standing position can be analyzed kinematically and kinetically, and the knowledge obtained can be used to structure experimental studies of recovery or loss of function in individuals with functional disability. Until recently, and despite the functional importance of rising, only a few studies of the kinematics and dynamics of rising have been reported in the literature. Nuzik et al. have made a first step in characterizing both the upper- and lower-body movement patterns of rising by documenting the mean angular positions of seven upper and lower body segments for 55 healthy individuals.

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adults using a cinematographic motion-analysis system. Their data provide insight regarding the general organization of movement of the body during rising to a standing position. Jeng et al. have demonstrated that subjects can perform this task in a similar manner under controlled conditions similar to those of the study of Nuzik et al.

A number of other investigators have documented characteristics of specific components of motion as individuals rise from a chair. Jones and colleagues have investigated the trajectory of the head in space under a variety of conditions, and they have identified the importance of what they termed head "balance" in determining the total head movement trajectory during rising. Fleckenstein et al. have demonstrated the influence of available knee range of motion on hip torque. Rodosky et al. used a Selspot optoelectronic system to investigate rising from a chair in 10 healthy individuals. These investigators described lower-body motions and torques (three body segments) as individuals rose to an upright position from chairs with seat heights varied in relation to the height of the participants' knee. Data from this investigation demonstrated that chair height is a significant factor in determining the maximum achieved angles of lower body segments, the excursion of body segments, and the torque developed in the lower extremity joints (hip, knee, and ankle). Pai and Rogers have characterized the control of center of mass (CoM) of the body as a function of speed of rising.

Each of these previous studies provides some insight into selected components of the activity of rising from a chair. None of the studies, however, provided a complete static and dynamic total-body analysis. Simultaneous analysis of forces and motions of the upper and lower body segments is necessary before the dynamics of rising can be interpreted completely. Furthermore, in many studies of the mechanics of rising from a chair, investigators have allowed subjects to rise under uncontrolled conditions. It is becoming increasingly evident that it is critical to control the initial position of subjects who are rising from a chair before comparisons can be made within or across subjects. Whether quantification of rising to a standing position is to be used as a functional task for clinical documentation of patients' status or for experimental analysis of patients, it is evident that the task should be carried out under controlled conditions.

The advent of systems using computerized stereography, such as the TRACK computer programs accepting position data from Selspot cameras, has made it possible to perform detailed total-body motion analysis with precision. The work of Rodosky et al. exemplifies a first attempt to use a detailed mechanical analysis to characterize rising from a chair, as performed by a small sample of healthy individuals. These investigators, however, carried out only a lower-body analysis of the movement and therefore could not draw conclusions regarding the total-body mechanics of rising. Thus, they were unable to analyze the role of the upper body on rising to a standing position, but rather were limited to a unilateral, two-dimensional depiction of the lower extremity in flexion and extension.

The purpose of this preliminary descriptive study was to characterize the dynamic events that occur as individuals rise from a sitting position to a standing position. Our specific aim was to characterize the mechanically distinct phases that occur during this functional activity. The Selspot TRACK optoelectronic motion-analysis system was chosen to study nine healthy, young individuals as they stood from a sitting position under highly controlled conditions. We examined the maximum values achieved and the timing of maximum joint angles, velocities, and torques of specific upper and lower body segments. These events are referred to as key events in the remainder of this article.

Total-body mechanical analysis provides clinical insight regarding implications of different strategies that physical therapists teach patients to use when rising from a chair. By characterizing rising under highly controlled conditions, it will be possible to determine the effect of normal aging or of specific pathologies on the mechanics of rising. It will also be possible to extend the work of previous investigators in identifying the total-body effect of altering various initial conditions of rising such as chair height, speed of rising, and initial foot placement.

Method

Subjects

Nine healthy women participated in this study. The subjects' ages ranged from 25 to 36 years (\(\bar{X} = 28.9, SD = 3.4\)), their height ranged from 152.4 to 175.3 cm (\(\bar{X} = 161.0, SD = 8.9\)), and their weight ranged from 47.6 to 65.8 kg (\(\bar{X} = 55.3, SD = 5.3\)). None of the participants reported prior musculoskeletal or neuromuscular disease or injury. All subjects signed an informed consent statement prior to participating in this study.

Instrumentation and Data Acquisition

Instrumentation included four Selspot II optoelectronic cameras; light-emitting diodes (LEDs); two Kistler piezoelectric force platforms; TRACK software; a PDP 11/60 minicomputer; a Vaxstation II work

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*Selective Electronics, Partille, Sweden.

1Developed at the Massachusetts Institute of Technology, Cambridge, Mass.

2Kistler Instruments AG, Winterthur, Switzerland.

3Digital Equipment Corp., 146 Main St, Maynard, MA 01754.
stations, and an armless, backless chair of adjustable height. Multiple LEDs were embedded in fixed arrays, which were then anchored to 11 body segments using polypropylene molds or neoprene bands (Fig. 1). Arrays were affixed bilaterally to the subject’s feet, shanks, thighs, pelvis, trunk, and upper arms. A single array was affixed to the head (Fig. 1). The TRACK® captures the 6-degrees-of-freedom motion (three translations and three rotations) of individual body segments. It requires no manual intervention and includes several automatic error-detection routines. Antonsson and Mann demonstrated that the Selspot® I/TRACK® optoelectronic system yielded displacement measurements accurate to ± 1 mm and rotation measurements accurate to within 1 degree. Testing of the Selspot® II/TRACK® optoelectronic system at the MGH Biomotion Laboratory (Boston, Mass.) verified that this system achieves at least the same accuracy.

In this study, the Selspot® II cameras sampled the subjects’ whole-body movements at a rate of 153 frames per second. Joint flexion angles were calculated by the TRACK® from the long axis of adjoining body segments. Joint angles were computed using Cardan angles, as described by Tupling and Pierrynowski. Net joint torques were calculated using NEWTON® software, developed by Antonsson. The CoM of the body taken as a whole was computed from contributions of each of the separate body segments, and the centers of pressure were computed from the force-platform data.

In this article, only the flexion and extension angles for the ankle, knee, hip, trunk, and head are reported. The position of the trunk was computed relative to the pelvis, and the position of the head was computed in relation to the trunk. Additionally, the absolute positions of the head and trunk were computed relative to the ground. Velocities for each of these body segments were computed by determining the rate of change with respect to time of the angle of the selected body segment. Representative plots of hip joint angle and angular velocity and of CoM and center of force (CoF) are presented in Figures 2 and 3, respectively.

**Procedure**

Participants were seated on the seat of an armless, backless chair, which was adjusted to 80% of each subject’s knee height, as determined by measuring from the floor to the anatomical joint line with the shank vertical. Participants were instructed to fold their arms across the chest and to rise without bringing their arms forward. Thus, use of the arms did not contribute to the upper-body momentum. The participants were positioned with one foot on each force plate, with their feet parallel, 10.16 cm (4 in) apart, and flat on the floor. The subjects were positioned in 18 degrees of ankle dorsiflexion, as determined by the angle of the shank with the vertical plane, and with their knees pointed straight ahead and their hips in neutral abduction and rotation. The participants’ buttocks were on the chair seat, and their thighs were unsupported. The initial head and trunk orientations were not controlled. Participants were instructed to rise in time with the beat of a metronome, which was set at 52 beats per minute, requiring them to rise in 1.2 seconds. The principal investigator (MS) initiated the task with the command “ready, set, start, stand,” which
Time (sec)

Figure 2. Hip-flexion motion as one individual rises from a sitting position to a standing position, depicting both angle and velocity of hip flexion. (Phase I = flexion momentum; phase II = momentum transfer; phase III = extension.)

was given in time with the metronome. Participants were instructed to begin rising at the word "start" and to become fully erect at the word "stand." Participants practiced the task several times prior to actual data collection until visually their performance appeared to the investigators to be executed smoothly and in the proper time frame. Data were collected for two trials for each subject.

Data Analysis

The time of key events was referenced to the time at which the buttocks first began to leave the chair seat (T = 0). This event, which we have termed lift-off, was identified as the point at which the force vector of the participant first began to increase in a weight-bearing direction (Fig. 4). Lift-off was a clearly defined, discrete event that could be reliably identified by the investigators within three frames (ie, within 20 msec). By comparison, the start of the chair-rise motion was difficult to precisely define. The start of the rising motion, therefore, was indicated as occurring prior to lift-off. The average values of the two trials were used for all data analyses. Data for specific key events were excluded from the analysis when two acceptable trials were not available. Frequency of occurrence of key events was used to describe the degree of variation that occurred during each phase of rising. Right- and left-side comparisons were made using a Student's t test. Unpublished research in our laboratory conducted on 18 similar subjects (Schenkman M, Jeng S-F, Ikeda ER, et al; manuscript in preparation) indicated that we could obtain acceptable reliability for our measurements.

Results

Phases of Rising from a Chair

Based on an analysis of the data obtained, we divided rising from a chair into four phases (Fig. 4), marked by four events. The first
phase, designated the flexion-momentum phase (phase I), began with initiation of the movement and ended just before the buttocks were lifted from the seat of the chair (lift-off). Momentum is the product of mass and velocity and is related to the kinetic energy of the system. During phase I, the trunk and pelvis rotated anteriorly (toward flexion), generating upper-body momentum. The subject’s femurs, shanks, and feet remained stationary.

The second phase, designated the momentum-transfer phase (phase II), began as the buttocks were lifted from the seat of the chair and ended when maximum ankle dorsiflexion was achieved. (Timing of maximum ankle dorsiflexion was the same for the right and left ankles.) Momentum transfer occurred when the momentum of the upper body developed in the flexion-momentum phase was transferred to the total body and contributed to total-body upward and anterior movement. During phase II, the CoM traveled anteriorly and upward. The whole-body CoM reached its maximal anterior point shortly after maximum dorsiflexion occurred (Fig. 3).

The third phase was designated the extension phase (phase III). Phase III was initiated just after maximal ankle dorsiflexion and was completed when the hip first ceased to extend. Usually, when the hip ceases to extend, it begins small rotations between flexion and extension as stabilization is achieved (Fig. 2). As shown in Figure 2, there was a prolonged period of deceleration as the hip reached the end of extension. The point at which hip extension was completed was difficult to identify accurately using the plot of the hip angle. We therefore used the angular velocity of hip motion to define the end of phase III. Full extension corresponded to the point at which hip angular velocity first reached 0°/sec. During phase III, the knee-extension and head-flexion motions were also coming to an end.

The fourth phase of rising from a chair was designated the stabilization phase (phase IV). Phase IV began just after the hip-extension velocity reached 0°/sec and continued until all motion associated with stabilization from rising was completed. The end point of phase IV was not easily

Figure 4. Four phases of rising marked by four key events. Because the arms are modeled as single segments (using one array), the fact that the forearms are folded across the chest is not reflected in the figure. (Reprinted with permission of the American Physical Therapy Association.)

![Diagram of rising phases](Image)

Figure 5. Trunk motion of one individual plotted in relation to the pelvis and in relation to the ground. For this individual, trunk flexion reached a maximum level in relation to the pelvis during phase I (flexion momentum) of rising, but reached a maximum level in relation to the ground during phase II (momentum transfer). This pattern was seen in seven of the nine participants. (Phase III = extension.)
defined because the subjects in this study normally experience some anterior-posterior and lateral sway during quiet stance. We therefore did not specifically analyze phase IV in this study. For the purposes of this article and for calculations we have considered only phases I, II, and III.

For the nine subjects who participated in this study, the mean time to complete the task of rising from a chair with metronome timing of 52 beats per minute was 1.95 seconds (SD = 0.03). The mean time to complete each phase was as follows: flexion-momentum phase, 0.50 second (SD = 0.08); momentum-transfer phase, 0.33 second (SD = 0.08); and extension phase, 0.98 second (SD = 0.20). The momentum-transfer phase constituted the shortest of the first three phases of rising to a standing position at 18% of the time required to complete the first three phases. The flexion-momentum and extension phases occupied 28% and 54%, respectively, of the time required to complete the first three phases.

**Phase I—Flexion Momentum**

The primary event in the flexion-momentum phase of rising was the trunk and pelvis rotation forward into flexion. For seven of the nine subjects, the trunk flexed on the pelvis an average of 16 degrees and reached a point of maximum flexion relative to the pelvis during this phase (Fig. 5). For two subjects, there was no trunk motion relative to the pelvis; that is, the trunk and pelvis moved into flexion together. Characteristic timing of events for the subjects is depicted in Figure 6.

Because of the relationship between angular momentum and angular velocity, maximum angular velocity can be used to determine maximum angular momentum and thus to identify aspects of the propulsion phases during a movement. Maximum trunk-flexion angular velocity, hip-flexion angular velocity, and head-extension angular velocity were reached during the flexion-momentum phase (Fig. 7) and occurred almost simultaneously, with a difference of only 0.02 second between the means for the three events. Maximum head-extension velocity showed the greatest variability, both in timing and in order of occurrence.

**Phase II—Momentum Transfer**

The momentum-transfer phase began when the buttocks lifted off from the chair and was completed on attainment of the maximally forward-flexed position (Fig. 6). In this phase, maximum ankle dorsiflexion, trunk flexion, hip flexion, and head extension were reached. There was almost no difference between right and left sides for maximum hip flexion, maximum ankle dorsiflexion, and total knee extension (Table). Differences between the right and left sides were not significant at the hip, knee, or ankle.

In the momentum-transfer phase, the order of events was invariant for eight of the nine subjects. The sequence of events for these eight subjects was maximum hip flexion, maximum trunk flexion, maximum head extension, and finally maximum ankle dorsiflexion. For one subject, maximum head extension was achieved after the completion of phase II.

Maximum hip and knee torques were reached during the momentum-transfer phase. There was little difference between the right and left sides. The right-side maximum hip torque was 95% of the left-side maximum.
Figure 7. Mean velocity timing data for nine individuals, demonstrating that maximum velocity was reached during phases I (flexion momentum) and III (extension), but not during phase II (momentum transfer).

A transition from the flexion motion to extension motion occurred as the body displacement shifted from primarily an anterior direction early in this phase to an anterior and vertical direction later in the phase (Fig. 3). In the early portion of the momentum-transfer phase, flexion velocities of the trunk and hip were already decreasing, as was extension velocity of the head. These velocities reached 0°/sec during the second half of this phase, and the transition to vertical displacement (extension) was initiated. Therefore, the extension velocities of the trunk, hip, and knee and the flexion velocity of the head began to increase during phase II, although they generally did not reach their maximum values during this phase. Finally, a transition occurred from dynamic to quasi-static stability during this phase. At the beginning of the momentum-transfer phase of rising, the vertical projection of the CoM of the body was posterior to the CoF (Fig. 3), satisfying the criteria for dynamic stability. At the conclusion of this phase, the vertical projection of the CoM of the body moved close to the CoF, satisfying the criteria for quasi-static stability.

Phase III—Extension

The beginning of the extension phase was defined by the attainment of maximum ankle dorsiflexion. The completion of phase III was demarcated by the time at which hip-extension velocity reached 0°/sec (Fig. 2). In eight subjects, the knee-extension velocity also reached 0°/sec during the extension phase of rising. In one subject, knee extension was completed 0.06 second after hip extension was completed. Head flexion was the most variable of the three body segments that we analyzed during the extension phase of rising. For six subjects, the head-flexion velocity did not reach 0°/sec during this phase. However, for the three subjects who completed head-flexion motion during phase III, this was the first event to occur. The most common pattern of events was that initial knee extension was completed during the extension phase of rising and initial head flexion was completed after the extension phase was over. The second most common pattern of events was that head-flexion velocity reached 0°/sec, then knee-extension velocity reached 0°/sec, and finally hip-extension velocity reached 0°/sec, completing phase III of rising.

In the extension phase of rising, maximum hip, trunk, and knee-extension velocities and maximum head-flexion velocity were reached (Fig. 7). Elapsed time between the first and last events was 0.13 second. In phase III of rising, there was more variability in the order in which events occurred than in phase I. The time at which maximum head extension occurred showed the greatest variability.
**Table. Motion of Six Body Segments**

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**Discussion**

**Phases**

Four kinematically distinct phases were identified during rising from a sitting position to a standing position under the conditions of this study. Based on the analyses we have carried out, we hypothesize that a momentum-transfer strategy is used as healthy individuals rise from a sitting position to a standing position under the conditions of this study. The flexion-momentum phase is characterized by the generation of upper-body momentum while the subject remains seated; the total body is therefore inherently stable. This process can perhaps be best appreciated if the reader moves the upper body rapidly forward into flexion and then suddenly terminates the active forward motion. The initial forward movement generates momentum, which will continue to bring the body forward. This momentum is a function of the mass of the upper body and the velocity with which it moves. The total body remains inherently stable as much as it neither topples forward nor topples backward off the seat of the chair when motion is suddenly ceased. This situation can occur because the vertical projection of the CoM of the body remains over the base of support (buttocks on chair seat and feet on floor) while momentum is being generated.

The momentum-transfer phase is mechanically distinguishable from the flexion-momentum phase from several perspectives. First, during this phase the projection of the CoM of the body is moved from the initial base of support to the new base of support (feet on floor). Thus, the CoM of the body is moved anteriorly (and upward), and the area of support is greatly reduced during this phase.

A second mechanical distinction between phases I and II relates to the stability of the body. At initiation of phase II, the body begins to rely on dynamic stability. Dynamic stability is essential because the vertical projection of the CoM of the body is far from the CoF. Position and velocity of the CoM must be well-coordinated prior to the momentum-transfer phase so that dynamic stability is maintained. The concept of dynamic stability can be experienced if the reader attempts to suddenly terminate the task of rising from a sitting position to a standing position just after lift-off of the buttocks from the chair seat. Phase II is a transition phase in that it begins with dynamic stability of the body and ends with a position approaching quasi-static stability (vertical projection of the CoM close to the CoF).

The third kinematic issue is that during phase II, momentum appears to be transferred from the upper body to the total body, hence the designation "momentum-transfer phase." Momentum transfer, and its importance, can be understood by comparing two different strategies for rising from a sitting position to a standing position. In the first strategy (illustrated in this study), the velocity, and therefore the momentum, developed in the upper body prior to lift-off is harnessed or transferred to the total body. At lift-off, the total body is already moving with some velocity, that is, has momentum. In this strategy, lift-off can take place while the vertical projection of the CoM of the body is posterior to the new CoF (under the feet) such that the body is inherently unstable; the total-body momentum appears to reduce the amount of lower extremity muscle force that would be required had the upper body been at rest at lift-off. In the second strategy, the trunk is first flexed so that its mass is nearly over the feet prior to lift-off. The individual then pushes up to a standing position. Because the CoM of the body is brought over the area of support prior to lift-off, the body remains inherently stable at lift-off. In this example, the body begins to lift from the seat from zero velocity and hence from zero momentum.

The difference between these two strategies can be compared experientially in terms of the apparent effort needed to rise. The first strategy requires less apparent effort than the second strategy. If the task is attempted using these two strategies, it becomes apparent that an individual can use a momentum-transfer strategy only if he or she is also capable of controlling the forward momentum after lift-off. Otherwise, the body
would be propelled too far beyond the new base and would fall forward. We are currently further investigating the hypothesis that momentum transfer occurs under the conditions of this study through more detailed analyses of kinetic energy, momentum, CoM, and CoF profiles (Riley PO, Schenkman M, Mann RW, Hodge WA; manuscript in review).

The extension phase of rising is mechanically distinct from both the flexion-momentum and momentum-transfer phases. The major task of this phase is to translate the body vertically while in an inherently stable position (CoM over CoF).

In the first three phases of rising, the task is to translate body segments through space. In the stabilization phase, the task is to terminate translation of the body through space (i.e., return the body to its normal postural sway). The completion of this phase is difficult to ascertain because there is no easy method of reliably identifying the transition between the postural movements resulting from rising and normal postural sway. We are currently developing criteria for determining the termination of phase IV so that this important phase can be further investigated.

**Clinical Applications**

Clinicians' understanding of the phases of rising from a chair can help them to focus their observations on postural movements resulting from rising and to differentiate those movements from normal postural sway. By observing the characteristic kinematics used to accomplish each phase of rising, the clinician can form hypotheses regarding what strategies a particular patient is capable of using and can begin to interpret the reasons for choice of strategies. Specifically, the clinician can estimate how far posterior the CoM is when the patient lifts off from the chair seat. The clinician can also estimate how long the patient remains in a condition of dynamic stability (phase II). These estimates are based on how the trunk is positioned relative to the feet prior to lift-off.

Use of a momentum-transfer strategy appears to have several requirements. The patient must have adequate strength and coordination to generate sufficient upper-body velocity, and hence momentum, prior to lift-off from the chair seat. He or she must be able to use eccentric contractions to control trunk and hip musculature in order to slow the body's forward progression once lift-off occurs. Otherwise, the patient may fall forward during the momentum-transfer phase, which is one of dynamic stability. Finally, lower extremity joint integrity and strength must be adequate for the extension component of rising, which requires good concentric muscle control.

Patients may use a variety of alternative strategies to compensate for losses of any of these capabilities. The clinician can attempt to understand which impairments determine the specific strategy used. Is there loss of ability to generate initial momentum for phase I? If the patient pulls his or her body forward using the arms during phase I, is he or she unable to generate adequate momentum with the trunk and hip flexor musculature, or is the patient attempting to increase the upper-body momentum above what would normally be used in order to compensate for lower extremity dysfunction? If a patient does not use a momentum-transfer strategy, is it because he or she has inadequate eccentric control of trunk and hip extensor musculature for dynamic stability in phase II? Are there other balance impairments that preclude the patient from remaining in a dynamically stable situation for phase II? These are only a few examples of the types of questions clinicians might ask in attempting to interpret the strategies patients use as they rise to a standing position.

Once the clinician has formed good hypotheses regarding what strategies a patient can use and why, he or she is in a position to justify an intervention strategy. Some patients' impairments can be corrected; other impairments should be compensated for with appropriate alterations of strategy or with assistive devices. For example, appropriate strengthening or coordination retraining can be used to assist the patient in the task of rising from a chair. Appropriate chairs or assistive devices should be used to protect the joints of the lower extremity, if controlled coordination and strength cannot be feasibly achieved, given the nature of the patient's impairments. Analysis of each phase of the task of rising can assist the clinician in making the most appropriate decisions regarding intervention.

**Comparison of Results of This Study with Results of Other Studies**

Some results of this study can be easily compared with results of other studies, and some results cannot be compared because of the various conditions under which rising from a sitting position to a standing position has been investigated. Work from a number of laboratories demonstrates that the dynamics of rising from a sitting position to a standing position are affected by conditions under which the task is carried out, including position of the lower extremities, chair height, and speed of rising.

This study emphasized highly controlled conditions. We devised a system to characterize rising from a sitting position in a reproducible fashion so that we could later analyze differences between individuals with and without pathology. We are currently using this system to characterize changes in patients over time following surgical or rehabilitative intervention. We have therefore developed a system and protocol whereby demands of the task can be incrementally increased to an individual's biomechanical tolerance. In order to carry out such studies, it is critical to have a methodology in which the variables of the task are controlled.

Our unpublished analysis of repeatability of performance discussed pre-
viously indicated that subjects perform the task of rising from a chair under the conditions described in this study in a similar fashion across multiple trials. Total time to accomplish the first three phases of the task was considerably longer than the expected 1.2 seconds. The prolonged time for rising appears to be an artifact resulting from our demarcation of the end of phase III. There was a considerable period during which hip-extension velocity decreased but did not quite reach 0/sec. This period did not seem visible to the eye. We are currently exploring an alternative demarcation for the end of this phase.

Conditions for this study were based on preliminary observations of healthy individuals and patients with knee replacement performing the movement of rising from a chair. The conditions were intended to be within the range of typical performance characteristics for this task. We intended to control enough variables to achieve acceptable repeatability of performance but not to constrain the motion more than necessary. For this reason we did not constrain initial trunk or head position, nor did we direct the participants regarding their head position during the task.

We chose to preclude use of the upper extremities to generate upper-body momentum separately from the trunk for several reasons. First, we wanted to emphasize the role of the trunk in the dynamics of this task. Second, it would have been difficult or impossible to control the extent to which different individuals used the upper extremities as distinguished from the trunk. By contrast, it was easy to have all subjects combine upper extremity movement simultaneously with trunk movement. Finally, we have observed that healthy individuals frequently do not use the upper extremities separately from the trunk in rising to a standing position under normal daily conditions. Thus, we did not need to specifically analyze the arms in our data analysis as they moved with the trunk. They were, of course, still a factor in rising.

Some aspects of our data can be compared with those of prior investigators. For example, hip, knee, and ankle motion and hip and knee torque were generally comparable to those values reported by Rodosky et al.7 for subjects rising from a chair at 80% of knee height. However, our results differ slightly from those of Rodosky et al.7 in that our subjects did not need to scoot forward on the chair seat prior to initiating the rising activity. It was more difficult to compare our results directly with those of Nuzik et al.10 or Burdett et al.12 These investigators did not control chair height in relation to knee height. It is evident that rising from a chair is markedly affected by chair height, foot position, and rising speed.7,8,11,12

Our finding that maximum hip and knee torques occurred very near the time when the buttocks were lifted from the chair seat is consistent with data of Kelley et al.20 This finding is to be expected because the individual is becoming weight-bearing while the CoM of the body is nearing the maximum forward position over the support foundation.

Summary

Coming to a standing position from a seated position is one of the essential functional activities of daily life. Rising to a standing position under controlled conditions can be used to define and increase our understanding of this important activity. This study extends the observations of other investigators3-12 who have characterized rising to a standing position from a sitting position. Under the conditions of this study, we have defined four phases of rising to a standing position from a sitting position: flexion momentum (phase I), momentum transfer (phase II), extension (phase III), and stabilization (phase IV). Upper-body momentum is generated in the flexion-momentum phase and is transferred to the total body during the momentum-transfer phase. During the momentum-transfer phase, the body is inherently unstable and control of the mass of the body is achieved through use of momentum in combination with specific muscles. The forces acting on the body (as indicated by torque) reach their maximum level during this phase.

This quantitative characterization of rising can facilitate identifying and interpreting underlying impairments of individuals who have difficulty in standing from a sitting position. An understanding of the several phases of rising can aid the clinician in developing detailed, objective grades for each of the phases and for the overall activity. This specific objective analysis of the rising task can further the clinician's ability to interpret causes of a patient's disability for this activity. Some patients have impairments that will preclude following the specific strategy outlined in this article. Then, using the techniques emphasized in this study, clinicians may propose, analyze, and evaluate new strategies as to ease of accomplishments and ergonomic consequences.

Acknowledgments

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References

7 Rodosky MW, Andracchi TP, Andersson GB. The influence of chair height on lower limb
Schenkman and colleagues are to be commended for directing their efforts to study kinetic and kinetic characteristics of one of the fundamental tasks of daily life. We need to know as much about "righting" tasks that take us from one stable posture to another as we do about walking. The reason is that those who cannot rise to standing do not experience full physical independence.

This study was carried out using a biomechanical framework. The application of biomechanics to the study of movement in our profession is so well accepted that it sometimes appears that this is the only scientific way to approach movement analysis. Two attributes of the biomechanical approach to movement analysis are the precise detail of description that can be achieved and the computer technology that is available to support this method of analysis. Measuring forces and displacements, and then computing velocities, accelerations, and kinetic constructs such as momentum, provide us with increasingly precise and complex descriptions.

Schenkman and colleagues have extended our knowledge of this task by identifying additional components of the rising task that had not previously been delineated. This additional information was derived from their use of a platform that enabled measurements of force that could be used to calculate momentum. One of the interesting aspects of this work is the identification of what the authors term "phase II," which begins when weight is transferred from the buttocks to the feet and momentum carries the center of mass of the body forward. The breaking down of the movement into additional phases adds an element to our understanding that had not previously been described.

This new knowledge, however, is achieved at some expense, which I feel limits the generalizability of the authors' findings. When numeric expressions of force, displacement, and time are available at high sampling rates, the magnitude of the data generated requires a process of averaging, or "smoothing," the information. Sophisticated motion-analysis systems include software that carry out this process. The idea is to generate a representation of the movement pattern. Mathematical procedures are used to eliminate variability. Variability between and within subjects is considered "noise," or error in the measurement. This variability is minimized to identify the true signal in the data, which theoretically is best represented by average values.

My concern with this study lies with the processes that were used to smooth the data, which I believe began before the subjects were even seated in the chair. The subjects were all young adults who were consistent performers across trials of a task when compared with younger and older individuals.1-3 The chair was adjusted or normed to the subjects' leg length, and the back was removed. People and chairs come in different sizes, and, as the authors point out, the literature demonstrates that relationships among chairs and people contribute to variability in the sit-to-stand movement. The subjects' arms were crossed in front of the body, and they were asked not to use them. Although this process reduces variability, it also restricts natural arm movement that has been reported as...
characteristic of young, adult subjects. Furthermore, by not including measures of arm action, the authors strayed from what I would consider a description of whole-body movements in this task and may have wandered into the realm of relatively uncommon performance within the sit-to-stand task. Few people rise with the arms crossed in front of the body.

The subjects' feet were placed a set distance apart. This process, although ensuring the subjects' feet were on the force platform and adding "control" and consistency that will later allow comparison across studies, also gets rid of natural variability in the starting position, a factor demonstrated by Wheeler and colleagues to vary with age.

Despite the relative consistency of young adults when asked to perform multiple trials of a task, as a group adults demonstrate a high degree of interindividual variability. Kelley et al. in their study of 6 subjects, commented on the across-subject variability in the rising pattern. Their subjects were able to use the upper extremities in performance of the task, and they identified shoulder and hip flexion as two sources of variability in the rising pattern. When Nusik et al. reported the results of their study of the sit-to-stand movements of more than 50 subjects, variability in movement patterns was again noted across subjects. I would suggest that the expressions of variability are just as informative for us as therapists and need to be explored before resorting to techniques of controlling the movement and mathematical smoothing of data. I am concerned that the second phase of rising identified by Schenkman et al may not be a general characteristic of sit-to-stand movements that include different starting postures and relative seat heights.

I would suggest that 9 is an insufficient number of subjects of similar age. I am concerned that the second phase of rising identified by Schenkman et al may not be a general characteristic of sit-to-stand movements that include different starting postures and relative seat heights.

Do procedures designed to control subjects and their environments bring us closer to a meaningful description of rising motions? I would hesitate to propose they do at this point in our understanding of this movement pattern. The time is rapidly passing when we can legitimately use a sample of young adults to develop models of any movement pattern for clinical use with any group other than young adults. The hypothesis that variability in sit-to-stand movement is in part due to age-related processes has been investigated by comparing both elderly subjects and children with young adults. Those studies demonstrate that age differences do exist in the movement patterns used to rise from a chair. Five different arm patterns, three different head and trunk patterns, and three different leg patterns have been reported in a sample of just 10 young adults. These data demonstrate how very variable this movement pattern can be.

I would suggest, if the authors are going to use information such as that attained from this study to assess patients who have undergone knee replacement, that their normative data be generated using a relatively large number of subjects of similar age. I would suggest that 9 is an insufficient number of subjects to generate an average representation of any age group and that more than 30 to 50 subjects contributes very little to the descriptive process.

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References


Author Response

We appreciate Dr VanSant's thoughtful commentary on our work raising questions regarding the generalizability of this study. We are pleased to have this opportunity to respond to the comments of Dr VanSant, as there are some fundamental and conceptual issues that should be addressed. We will address the broad issue of choice of experimental approach and then discuss specific technical concerns that were raised.

Studies of human movement can be motivated by a variety of interests and questions. Some investigators have chosen to identify how people perform a particular activity during normal daily activities. These qualitative
and descriptive studies help us to appreciate the broad range of potential strategies that people use to carry out the same task. In this type of investigation, performance of the task is necessarily largely uncontrolled by the investigator. This approach is exemplified by the work of VanSant and colleagues.\textsuperscript{1-3}

Other investigators are motivated by a desire to explicitly quantify the biomechanical features and constraints of a particular functional activity. This approach provides the basis for biomechanical models, with the potential of providing scientific explanations for the myriad of human motor behaviors identified by the first type of study. The work of Pai and Rogers,\textsuperscript{4} Riley et al.,\textsuperscript{5} and Rodosky et al.\textsuperscript{6} illustrates this approach to the analysis of human behavior.

Some researchers have chosen to investigate performance of a task in order to make comparisons between groups of individuals or of the same individual over a period of time. Wheeler et al.\textsuperscript{7} and Ikeda and colleagues (E Ikeda, M Schenkman, PO Riley, RW Mann, WA Hodge; manuscript in review) have applied this approach to the functional task of rising from a sitting position to a standing position. When analysis of human movement is used to make comparisons, we believe it is essential that the task or activity be explicitly described and adequately controlled in order to ensure reproducibility.

Each approach makes a distinct contribution to our knowledge of human movement. These approaches are furthermore complementary. For example, our analysis of momentum transfer in the sit-to-stand activity permits us to define the biomechanical components of the task. Hence, we can infer which impairments might preclude use of the strategy. We can also interpret the reasons for the many strategies of motion performance described in studies such as those of VanSant and colleagues.\textsuperscript{1-3}

Our study was motivated by two of these three purposes. First, we wanted to establish a baseline for subsequent comparisons among individuals as they performed the sit-to-stand activity under controlled conditions. Second, we wanted to make this a quantified biomechanical analysis of a particular movement strategy by combining precise three-dimensional kinematic data with foot-floor forces. We therefore needed to use a controlled protocol.

Some of Dr VanSant's specific concerns relate to smoothing and averaging of the data. First, we contend that variability within and between subjects is not noise and therefore was not "smoothed out" by our processing techniques. Noise is spurious, unwanted additions to the true signal, which must be mitigated by techniques that engineers refer to as "smoothing" or "filtering.\textsuperscript{8} We used high sampling rates to reduce the need for smoothing. The authenticity of kinematic data is enhanced, rather than diminished, by use of a high sampling rate. Averaging is a separate issue. We chose not to average our subject data because we did not want to lose subject-to-subject or trial-to-trial variability. By reporting frequencies of key events achieved during all 18 trials, we described the variability that occurred.

Another concern of Dr VanSant related to our choice of protocol. The highly controlled protocol with a uniform group of subjects maximizes the likelihood of achieving a consistent performance of the sit-to-stand activity. As described in our article, the variables we controlled have been shown, by previously reported investigations, to alter performance of the sit-to-stand task. The results of this study, and those of a companion study,\textsuperscript{9} illustrate the consistent kinematic and kinetic performance of the subjects who carried out this task. The combined results of these two studies have allowed us to elucidate a biomechanical model of the sit-to-stand activity. Thus, we believe we have achieved one of our two purposes.

Having established our test-performance baseline, we were then able to address our second purpose, which was to make performance comparisons to the sit-to-stand activity under the conditions of this controlled protocol. To this end, we have completed a comparison of healthy young and older individuals (E Ikeda, M Schenkman, PO Riley, RW Mann, WA Hodge; manuscript in review) and are currently comparing the performance of patients with Parkinson's disease with that of healthy age-matched subjects. Our description of the biomechanics of this activity (presented in this article and in the companion study)\textsuperscript{9} provides us with the necessary basis for such comparisons.

To increase the generalizability of our investigations, we have also systematically varied some of the conditions under which subjects come to a standing position. For example, we have begun to study the influence of chair height, initial foot position, and speed of rising\textsuperscript{9} and are currently completing this investigation.

The sit-to-stand activity, as investigated in our article, has defined the necessary model for making objective, quantifiable comparisons between subjects. Through qualification of the kinematics and dynamics of the sit-to-stand activity, the laws of physics and mechanics can be applied to elucidate reasons for all of the limb-segment combinations of motion that investigators such as Dr VanSant have described.

In summary, this study should be read and interpreted from the perspective in which it was intended. Our motivation was to characterize an important, commonplace movement in such a way as to allow a biomechanical quantification of the task. This perspective precludes the use of our results to describe all possible strategies for rising from a chair. Our work does, however, allow us to use laws of mechanics and physics to interpret other descriptions of rising from a chair. Furthermore, our work allows us to make objective biomechanical comparisons between groups of individuals.
References


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