A kinematic comparison between elderly and young subjects standing up from and sitting down in a chair

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Abstract

Background and aims: the transfer from sitting to standing and back to sitting as the two phases of the same task has never been studied in elderly people. The purposes of this study were to analyse and compare kinematic features of the whole task (standing up and sitting down) and to determine whether there are age-related differences upon movement kinematics in healthy elderly persons during the whole sequence (standing up and sitting down).

Methods: the movements of various parts of the body were measured with a 100 Hz television image analyser that computed the co-ordinates of small reflective markers glued onto the skin of the subjects. The task was conducted using an armless chair set to 100% of knee height under four conditions: at normal speed in light, at normal speed in the dark, at fast speed in light and at fast speed in the dark.

Type of study: laboratory study.

Results: in young subjects, the task was characterized by similar acromion trajectories and angular displacement of trunk in standing up and sitting down and by a stabilization of the head in space during the two phases. However, the time required to achieve the movement was found to be greater in sitting down than in standing up, and an adjustment of velocity appeared in final part of the movement before reaching the chair. In sitting down, as in carrying out a pointing task of upper limb, an adjustment was required to achieve accuracy. This feature was not found in standing up. Age-related differences appeared to be more important during sitting down than during standing up. Moreover, deterioration of head stability was found in elderly subjects, particularly when the task was achieved rapidly and in darkness.

Conclusion: there is a relationship between changes in the motor control of the task, which appeared during periods of potential postural instability, and the effects of ageing on postural stability.

Keywords: ageing, kinematics, posture, sitting, standing

Introduction

The effects of ageing on postural control and their consequences for functional dependence and the risk of falling have been well documented [1]. In many epidemiological and clinical studies, the capacity to stand up from a chair has been regarded as an important indicator of an elderly person's functional independence [2] and as a predictor of falls [3]. The longer it takes some people to stand up, the worse score they achieve on balance tests [4].

Standing up is a complex task characterized by the transfer from one stabilized posture to another with movements of all body segments except the feet. The transfer from sitting to standing and back to sitting requires both voluntary movement of the different segments that contribute to the change of posture and equilibrium control during an important displacement of the body centre of gravity. It is characterized by displacing the centre of gravity forward then backward with simultaneous vertical displacements. Consequently, the whole movement (standing up and sitting down) is an effective paradigm by which to study the co-ordination between posture and movement. Most
studies linking posture and movement in ageing subjects have analysed anticipatory postural reactions during movements of the arm, which are more slowly activated [5, 6]. Kinematics of these postural responses have also been studied using a moving platform, which showed differences in magnitude and temporal sequencing of body segment motion between healthy elderly subjects and young controls [7].

Schenkman et al. [8] studied standing up in young people to identify the different phases of the movement from kinetic and kinematic data. Using a similar analysis, Rilley et al. [9] discussed the contribution of the trunk to the displacement of the centre of gravity. Seedholm and Terayama [10] and Rodosky et al. [11] showed that the use of a high seat and a push on the hands resulted in a decrease in the hip and knee joint torques. Balance control during standing up has been studied using changes in execution speed and terminal constraint with modifications of standing posture [12, 13]: the control of the centre of gravity in a horizontal direction represents an important variable of dynamic balance during the task. Studies of the chronology of the whole movement (standing up and sitting down) from force platform data show that it takes longer to sit down than to stand up [14].

The first purpose of our study was to analyse and compare kinematic features of the whole task (standing up and sitting down) in order to understand whether the two phases of the movement (against and with gravity) are based upon separate planning processes. These two movements, which present different dynamic constraints, are a priori not similar. Nevertheless, the to-and-fro specificity of the experimental task could involve similar planning processes [15].

The second objective was to analyse age effects on movement kinematics in healthy elderly persons during the whole sequence (standing up and sitting down). Previous studies on elderly subjects have been performed with comparison with young subjects, but sitting down has not been considered.

Studies on standing up have presented the results in terms of age-related changes of the maintenance of postural control: Hughes et al. [16] showed the importance of both foot position and centre of gravity velocity in controlling stabilization at seat-off. Alexander [17] suggested that the main kinematic differences between young and elderly subjects concerned the first sequence of standing up movement, defined as start to rising from the seat. These results were interpreted in terms of deficient postural stability.

To clarify ageing effects, we have identified kinematic changes in elderly subjects, during both standing up and sitting down. The two phases of the movement (standing up and sitting down) are analysed from kinematic data under different experimental conditions of speed and light in young and elderly subjects.

**Methods**

**Subjects and experimental paradigms**

Data were obtained from seven healthy young subjects aged between 20 and 25 years (mean = 22.8, SD = 1.5) and five healthy older subjects aged between 71 and 82 years (mean = 73.2, SD = 5.5). The young subjects were physiotherapy students. Older subjects were recruited from a senior citizens' club. Potential elderly subjects were screened to exclude any neurological diseases or musculo-skeletal conditions which could have limited motion. All subjects were volunteers who gave informed consent.

Subjects were seated on an armless chair set to 100% of the knee height. A back support was used to set the trunk in a vertical position. The arms were folded across the chest. The feet were placed flat on a force platform, 10 cm apart at the heels with the shanks positioned in 20° flexion relative to the vertical. Subjects were instructed to stand up from the chair, to maintain an upright standing position for 2 s and to sit down again. Two visual conditions (light and darkness) and two speeds (normal and as fast as possible) were tested using four experimental conditions: light, normal speed; darkness, normal speed; light, rapid speed; darkness, rapid speed.

**Recording system and data analysis**

The movements of specific sites of the body were measured using a 100 Hz opto-electronic movement analyser that computed the co-ordinates of small reflective markers (0.5 cm in diameter) glued on to the subjects' skin. Two cameras were located at 1 m and 2 m from the ground on the left side of the subject and 3 m from the sagittal plane of the movement. Eight markers were fixed on the left side of the body at the following sites:

1. The head, at the level of the external canthus of the eye and the auditory meatus. The link connecting the two markers allowed us to determine the position of the vestibular system with respect to gravity because it defines the Frankfurt plane, which is located at 30° below the plane of the horizontal semi-circular canal (see [18]).
2. The trunk, at the level of the acromion and between the armpit and the mid-iliac crest at the level of the inferior angle of the scapula.
3. The lower limb, at the level of the hip (trochanter), the knee (interstitial joint space), the ankle (external malleolus) and the foot (fifth metatarsophalangeal).

Kinematic parameters in three dimensions were calculated from successive frames taken at 10 ms intervals. Under these conditions, in which the observed field of view was 1.5 m × 2 m, the accuracy was 1-1.5 mm for linear displacement and 1.5° for angular positions.
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From the position of the markers four angles were calculated and analysed:

1. The spatial angle between the trunk (the link between the acromion and the trochanter marker) and the vertical plane.
2. The angle between the Frankfurt plane and the vertical plane.
3. The angle between the Frankfurt plane and the trunk.
4. The angle between the thigh (the link between the trochanter and the interstitial joint space of the knee) and the shank (link between the knee and the external malleolus).

Figure 1 shows a stick-diagram in a young subject reconstructed by the computer from the eight markers placed on the body.

The beginnings and the ends of each phase were calculated from the angular velocity of the trunk. The movement duration was defined as the time between the first value of angular velocity of the trunk forward bending which exceeded 10% of its maximum value and the last value of angular velocity of the trunk backward returning which was lower than 10% of its maximum value.

The vertical linear displacement of the trochanter marker was used to identify the seat-off and seat-on events.

To analyse the velocity profiles, the symmetry index (K) was calculated by dividing the time to peak velocity by movement duration [19]. A ratio greater than 0.5 indicated an acceleration duration longer than deceleration duration.

For each subject, the mean of the three trials was used as the criterion for subsequent data collection.

The two groups were compared through the different variables with a three-way (phase, vision, speed) 2 x 2 x 2 factorial analysis of variance (ANOVA). For any significant (P < 0.05) interaction, the means were compared post hoc 2 x 2 with the Newman-Keuls procedure. For any non-significant (P > 0.05) effect, the Student 95% confidence intervals based on the residual variance were computed for the differences of the corresponding means, in order to estimate the size of a possible difference (and thus to detect if non-significance might be caused by ANOVA lacking power).

Results

Kinematic analysis in young subjects

The main characteristics of each movement phase were first analysed in young subjects. The two groups were then compared under different experimental conditions.

General characteristics of the task

These were analysed both from acromion and trochanter trajectories and linear velocities.

The trajectories in the sagittal plane of the acromion and trochanter markers during standing up and sitting down are shown in Figure 2. During standing up the trajectory of acromion was made up of a horizontal segment and then a vertical one. During sitting down the pattern was inverted, with a first vertical sequence and a second horizontal one. For both standing up and sitting down, vertical and horizontal sequences were linked by a small curved trajectory. The two traces were superimposed, indicating a similar shape for the two movements performed against and with gravity.

For the trochanter, upward and downward movements were similar in shape but the similarity was less marked. The paths were approximately orientated...
Figure 3. Acromion and trochanter linear displacements as a function of time during standing up and sitting down: acromion along A–P axis and trochanter along vertical axis. The shaded boxes correspond to motion sequences between starting and finishing standing up (left) and sitting down (right). Shaded boxes indicate the initial and final positions. Arrows indicate the direction of the movement. STS, sitting to standing; BTS, back to sitting.

along a diagonal with a negative slope, indicating a simultaneous movement of the trochanter along the horizontal and vertical axes. In contrast, the beginnings and ends of the traces were horizontal due to an antero-posterior movement of the trochanter. During sitting down it can be noted that the path passes behind the standing up one.

The events were analysed from displacement velocities of the acromion and trochanter respectively in antero-posterior and vertical planes (Figure 3).

For the standing up phase, the movement started with a forward translation of the acromion followed by an upward displacement of the trochanter. The forward displacement of the acromion continued after seat-off. A small backward movement of the acromion preceded the standing posture. Thus, the need to control trochanter lifting and antero-posterior displacement of the trunk simultaneously represented the main co-ordination during the sequence which started at seat-off and ended when the subject reached standing posture.

The same type of co-ordination between acromion along x and trochanter along z can be observed during sitting down. Forward displacement of acromion started just before the downward displacement of trochanter, then the backward displacement of the acromion preceded seat-on.

Head and trunk angular displacement
Mean position of the head was calculated by considering the angle of the Frankfurt plane with the earth vertical. Head stability in the sagittal plane was evaluated by considering the standard deviation of head angular displacement [18] during the whole movement. Mean values of standard deviations in all subjects and experimental conditions were not greater than $5.4 \pm 0.8^\circ$. Mean positions of the Frankfurt plane remained near the horizontal plane: $89 \pm 5^\circ$, ranging from $77^\circ$ to $99^\circ$.

Trunk angular displacements during standing up and sitting down were $32 \pm 9^\circ$ and $8 \pm 9^\circ$ respectively. Figure 4 depicts the forward trunk angular displacement partially compensated for by neck rotation in order to maintain the Frankfurt plane close to the horizontal plane.

Velocity profiles
Figure 5 depicts trunk and knee velocity profiles.

During standing up, trunk angular velocity profiles of young subjects consisted of two loads linked without discontinuity and corresponding to forward bending (a negative load) and backward returning movement of the trunk (a positive load). Knee velocity profiles were unimodal. The beginning of knee angular displacement corresponded to the peak value of trunk forward bending. Maximum knee angular velocity corresponded to maximum backward angular displacement of the trunk.

In contrast, during sitting down, trunk and knee velocity profiles of young subjects were less regular in shape. Trunk velocity profiles were not so well linked, the deceleration phase of forward bending and the acceleration phase of the backward returning movement were not on a continuous slope. In other words, an abrupt change in angular velocity appeared during the transition between the end of trunk forward bending and the start of trunk backward returning movements. In addition, the transition between forward and backward trunk movements were associated with a discontinuity in knee flexion. Maximal angular velocities of trunk forward bending were $86 \pm 17^\circ$/s (standing up) and $95 \pm 21^\circ$/s (sitting down) and of trunk backward returning $82 \pm 15^\circ$/s (standing up) and $75 \pm 11^\circ$/s (sitting down) respectively. For the knee, maximal angular velocities were $156 \pm 28^\circ$/s and $142 \pm 23^\circ$/s, for standing up and sitting down respectively.

Relative durations of acceleration and deceleration were examined using the index $K$. The variability of $K$ around 0.5 indicated asymmetric velocity profiles of knee angular displacement. During standing up the knee extension index was $0.60 \pm 0.05$ in young subjects, indicating a greater duration of the acceleration phase compared with the deceleration phase. In contrast, during sitting down the value decreased to $0.40 \pm 0.06$, demonstrating a reversed pattern to standing up. The index of $K$ failed to measure the symmetry in the trunk velocity profiles because the aspect was bimodal in elderly subjects.
Comparison between the two groups under the different experimental conditions

No differences between young and elderly subjects were shown through the qualitative analysis of acromion and trochanter trajectories.

Task duration

Figure 6 gives the duration of each phase in the two groups under the different experimental conditions. In young subjects under normal conditions, the duration was 1.31 ± 0.11 s (standing up) and 1.40 ± 0.15 s (sitting down). In elderly subjects the durations were 1.33 ± 0.24 s and 1.69 ± 0.31 s.

There was a significant main effect of phase \( F(1,10) = 30.6; P = 0.0002 \). In both groups sitting down duration was found to be greater than standing up duration. Elderly subjects spent a greater time performing each phase than young subjects \( F(1,10) = 6.62; P = 0.02 \).

No significant effect of vision was found \( P = 0.6 \). The level of confidence calculated for the difference between light and darkness indicated that the difference did not exceed 12%.

Trunk rotation and head stability

No significant group difference was noted in trunk rotation in space, phase \( P > 0.05 \), visual acuity \( P > 0.05 \) or speed \( P > 0.05 \).

Head stability (Figure 7) tended to be poorer in elderly subjects, but the difference between the groups only reached statistical difference for rapid movement and darkness conditions. In this case a significant interaction of age x vision x speed was found \( F(1,10) = 16.8 \ P = 0.002 \). For rapid movement in darkness, head stability decreased in elderly subjects whereas it was improved in young subjects. The coefficients of variation were very high in elderly subjects (0.50 under normal conditions).

Velocity profiles

For standing up, trunk velocity profiles in elderly subjects were less smooth than in young subjects, with numerous accelerations, particularly after seat-off and during the acceleration phases orientated in the opposite direction to gravity (forward bending deceleration and backward returning acceleration). Similarly, there was a change in knee angular velocity at the start of the deceleration phase of trunk forward displacement after seat-off (see Figure 5).

In sitting down, the main differences between young and elderly subjects were shown during the deceleration phases of knee flexion and trunk backward returning movements.

Statistical analysis of maximal angular velocity of the trunk during forward bending showed a significant age x phase \( F(1,10) = 10.3; P < 0.009 \) interaction: in elderly subjects, angular velocity of trunk forward bending was smaller during sitting down than during

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Figure 4. Typical data of angular displacements of trunk (—) and head (—) related to the vertical plane and head related to trunk (—) for a young subject during standing up and sitting down. Shaded boxes indicate the initial and final positions. The vertical dotted lines correspond to starting to stand up (left) and finishing sitting down (right). STS, sitting to standing; BTS, back to sitting.
standing up. This was not the case in the young subjects. The age × speed interaction was also significant [F(1,10) = 6.37; P = 0.05]: in the young subjects, angular velocity of trunk forward bending during standing up and sitting down, significantly increased in rapid conditions; in contrast, no difference was found between normal and rapid conditions in the elderly subjects (P > 0.05).

For angular knee velocity, the age × phase interaction was significant [F(1,10) = 5.94; P = 0.03]. The differences between the two phases were not significant in young subjects (P > 0.05) whereas, in the elderly subjects, maximal angular knee velocity during sitting down was smaller than during standing up. This difference between phases was significant, as shown by post hoc comparison, for all vision and speed conditions (P < 0.05).

The age × phase interaction was also significant for the index K of angular knee velocity [F(1,10) = 9.97; P = 0.01]: this indicated a greater deceleration time in sitting down than in standing up, the difference between the two phases being larger for elderly subjects (Figure 8).

Discussion

This small study of a kinematic analysis describes the differences in movement related to age both in temporal and spatial domains, during standing up

Figure 5. Typical angular velocity profiles of the trunk (——) and the knee (——) for one younger (top) and one older subject (bottom). The arrows indicate seat-off and seat-on events and the dotted circles indicate main modifications of velocity profiles in elderly subjects. TFB, trunk forward bending; TBR, trunk backward returning; KE, knee extension; KF, knee flexion. STS, sitting to standing; BTS, back to sitting.
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Figure 6. Mean values with standard deviations of execution time in young (○) and elderly (●) subjects a standing up and b sitting down under different experimental conditions: normal speed and light (LN), rapid speed and light (LR), normal speed and darkness (DN) and rapid speed and darkness (DR).

General characteristics of the two movement phases

If trunk angular displacements in space are considered, standing up and sitting down can be regarded as a 'to-and-fro' movement. This is because, although the initial position and mechanical conditions related to gravitational effects differ between standing up and sitting down, acromion trajectories in the sagittal plane show similar forms. Thus, up and down acromion trajectory does not vary in movement planning.

This was not found for the trochanter. Unlike the acromion, trochanter trajectories appeared as a variable which was regulated as function of the gravitational and postural constraints of each phase.

During both standing up and sitting down, trunk angular displacement with respect to the vertical remained constant.

The control of the trunk segment is widely involved in maintaining upright posture during voluntary tasks [21]. During each phase, trunk displacements in forward direction could create disequilibrium. For the movement of standing up, forward trunk rotation at the beginning of the movement contributes greatly to the horizontal momentum of the centre of gravity [13]. In sitting down, forward trunk rotation may contribute to stability control along the antero-posterior axis.

However, during the two movement phases, the trunk, movable in space, cannot be considered as a stabilized reference used for postural control [22] as previously demonstrated during leg [23] or arm movements [24]. Conversely, the head can be used as a reference frame. Our results show a minimization of head rotation during the two phases. These results confirm the previous studies [18, 25] that have demonstrated good head angular stabilization relative to other limbs in the sagittal plane during locomotion and other goal-directed tasks, and in the frontal plane during dynamic equilibrium tasks [26]. One advantage of head stabilization during dynamic equilibrium is to introduce constraints in the relation between extrinsic (vertical) and intrinsic (head position with respect to
The execution time of the two phases was found to be different, being greater in sitting down that in standing up (as in the study of Kralj and co-workers [14]). However, our results tend not to agree with this group, who suggest that the difference can be explained by both braking required against gravity effects and a lack of visual information during sitting down. This idea implies that in the dark, the time taken to stand up increases; this was not the case in our study. The time required to achieve sitting down seems to be more related to features of the task than to a lack of visual information. The study of velocity profiles of the knee showed an adjustment during the terminal sequence of sitting down not found in standing up. This difference in velocity profiles during standing up and sitting down may be explained if a comparison is drawn between sitting down and pointing movements. The velocity adjustment seen when the buttocks near the seat resembles the final adjustment observed in arm reaching movements [27]. Previous studies have analysed pointing tasks and shown that adjustments are made during the terminal phase of the movement in order to localize the target [28]. In the same way, it may be expected that this type of terminal adjustment be used also in order to reach the chair. In the absence of visual feedback, the execution of standing up which precedes sitting down in our experiment allows the memorization of the position and the height of the chair. Thus, the accuracy required in the final part of sitting down could explain some differences found in execution time for the two movement phases.

Moreover, the absence of visual information during standing up and sitting down does not influence subjects' performance, suggesting that the two tasks are mainly dependent upon somatosensory information.

**Effects of age and experimental conditions on the whole movement**

The recorded trajectories were found to be identical in young and elderly subjects. This suggests that the geometrical parameters of the movement studied are not modified by normal ageing.

On the other hand, elderly subjects required more time than young subjects to achieve the task. Generally considered a feature of ageing [29], motor slowing has been studied during psychomotor tasks [30] and in complex activities such as gait [31]. Different explanations have been suggested according to which movement was studied: an increase in reaction time [32], the alteration of latencies of preparatory postural adjustments [33] or a decrease in muscular strength [34]. In our study, the lack of modifications of velocity profiles of the knee during rising from a chair suggests that a decrease in muscular strength cannot account for increases in time. During standing up and sitting down, motor slowing observed in elderly people seems to be related more to postural control since the perturbations of velocity profiles of the trunk and knee become apparent just after seat-off in standing up and just before seat-on in sitting down. These sequences can be analysed as periods of potential postural instability during which the trunk moves simultaneously along anterio-posterior and vertical axes.

Independently of execution time, there are differences between the two groups in terms of postural control. Thus, in rapid conditions, maximal angular velocity of trunk flexion remained constant in elderly subjects during standing up and sitting down, whereas it increased in young subjects. This can be interpreted as a way of minimizing the effects of destabilization generated by rapid displacements of trunk.

Sitting down, which requires fine postural control and accuracy in the final part of the movement, is more affected by ageing. The results of maximal angular velocity of knee and braking time show that elderly people have to control the critical part of the movement much more than young subjects. This important need for an adjustment of velocity confirms the findings of Morgan et al. [35] with precision tasks of the upper limbs, which they regarded as modifications of motor control during ageing. Young subjects use the same velocity in forward displacements of the trunk during standing up and sitting down independently of the initial position, whereas the maximal velocity of the trunk was smaller during sitting down in elderly subjects. The simultaneous comparison between the two phases and the two groups makes it possible to observe that elderly subjects demonstrate fewer similarities between standing up and sitting down than young subjects do. During sitting down, elderly subjects needed greater velocity control to maintain the equilibrium in an upright initial position and to achieve accuracy before the contact with the seat.

Finally, in elderly subjects the study of head rotation showed a non-significant trend of decreasing stabilization in space due to a large dispersion of the values. The difference between young and elderly subjects became significant when the task was achieved rapidly in darkness. The vestibulo-ocular, cervical and visual reflexes contribute to the control of the head in space during body motion. In elderly adults, head stabilization can be affected either by the deterioration of the vestibular organs [36] or by modifications of cervical proprioception [37]. These deficits can be compensated for by other sensory inputs: visual and cervical proprioception. In our study the instability of the head in space appeared obvious, while sensory deprivation was associated during rapid conditions. This double condition may lead to a lack of compensation of vestibular input with visual input and to difficulties in detecting somatosensory messages. The deterioration of head–trunk co-ordination affects postural control.
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during the achievement of standing up and sitting down.

In spite of some similarities of trajectory shape during standing up and sitting down (particularly in the control of trunk displacements), knee angular displacement showed substantial differences between the two phases, mainly due to terminal constraints. In elderly subjects modifications of kinematic parameters can be interpreted as alterations of postural control. Head stability, which was identified in young subjects as a characteristic of the task, was found to be unreliable in elderly subjects. Furthermore age-related differences appeared much more obviously in sitting down than in standing up.

The great amount of data supplied by systems of motion analysis makes it difficult, even today, to apply them to large groups. However these data provide a basis for further studies which will be able to (i) analyse the kinematic features of standing up and sitting down in disabled subjects and (ii) assess rehabilitation effects.

Clinical implications of these results are potentially interesting, particularly in elderly subjects showing alterations of posture and gait after falls [38]. These subjects are characterized by an incapacity to mobilize the trunk correctly during standing up and sitting down. This incapacity both makes it difficult for them to stand up and can cause them to fall backwards when sitting down.

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Key points

- Transfer from sitting to standing and standing to sitting is a task that can be studied by kinematic recordings.
- Old and young subjects take longer to sit down than to stand up.
- Older people sit down more slowly than younger people.
- Fine postural control and accuracy decline with age.
- Alteration of head stability occurs in elderly subjects when the task is achieved rapidly and in darkness.

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