A kinematic and kinetic analysis of the sit-to-stand transfer using an ejector chair: implications for elderly rheumatoid arthritic patients

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Abstract

Twelve elderly female rheumatoid arthritis patients (mean age = 65.5 ± 8.6 yr) were assessed rising from an instrumented Eser Ejector chair under four conditions: high seat (540 mm), low seat (450 mm), with and without the ejector mechanism operating. Sagittal plane motion, ground reaction forces, and vertical chair arm rest forces were recorded during each trial with the signals synchronised at initial subject head movement. When rising from a high seat, subjects displayed significantly (p < 0.05) greater time to seat off; greater trunk, knee and ankle angles at seat off; increased ankle angular displacement; decreased knee angular displacement; and decreased total net and normalised arm rest forces compared to rising from a low seat. When rising using the ejector mechanism, time to seat off and trunk and knee angle at seat off significantly increased, whereas trunk and knee angular displacement, and total net and normalised arm rest forces significantly decreased compared to rising unassisted. Regardless of seat height or ejector mechanism use, there were no significant differences in the peak, or time to peak horizontal velocity of the subjects’ total body centre of mass, nor net knee and ankle moments. It was concluded that increased seat height and use of the ejector mechanism facilitated sit-to-stand transfers performed by elderly female rheumatoid arthritic patients. However, using the ejector chair may be preferred by these patients compared to merely raising seat height because it does not necessitate the use of a footstool, a possible obstacle contributing to falls. © 1998 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Rising from a chair is a common activity of daily living. However, many elderly people, in particular, those with rheumatoid arthritis (RA), often have difficulty rising from a chair. Consequently, these individuals have problems living independently and risk institutionalisation. The ability of the RA patient to rise from a chair may be restricted by pain, stiffness, reduced joint range of motion, muscle weakness, and incapacitation due to joint deformity (Scott, 1978). Questionnaires completed by 379 elderly patients, 48.5% of whom were afflicted with RA, found that 42% of all patients questioned experienced difficulty when rising from a chair (Munton et al., 1984). Therefore, modified chairs which facilitate the rising process may benefit the elderly RA patient.

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the STS transfer, is currently prescribed to elderly and/or disabled patients who have difficulty rising (Bashford et al., 1994). The mechanical ejector device incorporated in the Eser Ejector chair provides an upward and forward force vector to the patient to assist them to stand. It has been claimed that the forward component of this force vector is potentially destabilising, thereby making such ejector devices potentially dangerous to the user (Bashford et al., 1994). Despite this claim no research was located which examined elderly or RA patients rising from a mechanical ejector chair. Therefore, the purpose of this study was to assess the effects of using the Eser Ejector chair, at two different seat heights, with and without the ejector mechanism operating on the mechanics of the STS transfer performed by elderly RA patients.

2. Methods

2.1. Subject selection

Twelve elderly females (mean age = 65.5 ± 8.6 yr; mass = 65.6 ± 18.0 kg; height = 1.59 ± 0.54 m) diagnosed with RA (19.0 ± 13.2 yr) participated in the study. Subject selection was based on the following criteria:

1. a score of 80 or above on the Modified Barthel Index which assesses level of independence in performing activities of daily living (Shah, 1986);
2. a score of 30 or above on the Australian Activities Index which rates level of physical activity performed in one week (Bond et al., 1994);
3. 50 years and above with no other major pathologies unassociated with RA which would significantly influence their ability to rise from a chair;
4. had been diagnosed with RA for at least five years but were not in acute pain at the time of testing; and
5. ability to rise from the Eser Ejector chair unassisted under all experimental conditions.

Informed consent was obtained from all subjects before the screening process. All testing was conducted according to the NHMRC Statement on Human Experimentation (National Health and Medical Research Council, 1993).

2.2. Experimental protocol

Each subject performed a STS transfer using the Eser Ejector chair (Legend Furniture, NSW, Australia, Model A34) (Fig. 1) under four conditions: high seat (540 mm) and low seat (450 mm), with and without the ejector mechanism operating. These seat heights were chosen as they were the lowest and highest settings available on the adjustable legs of the chair. Subjects were positioned before each trial with their buttocks as far back as possible on the seat, their back resting against the backrest of the chair, and their head upright with eyes focused forward (Fig. 1). Each subject was verbally instructed to stand using a natural rising motion. The only constraints on the rising motion were that subjects were required to use the chair arm rests and keep their feet on the force platform throughout the STS transfer. Each trial was terminated when subjects were in an erect standing position.

Fig. 1. Subject seated in Eser Ejector chair in standardised start position with joint markers, chair markers, and scale markers shown.
position, independent of the ejector chair, and the velocity of their centre of mass (CoM) was zero. Three successful trials were recorded for each condition with adequate rest provided between trials to prevent fatigue. When completing each trial, subjects estimated the effort of rising using the Rating of Perceived Exertion Scale (RPE) (Borg, 1970) and their pain level using the Visual Analog Scale (VAS) (Huskisson, 1974).

After becoming familiarised with the STS task, sagittal plane kinematics, ground reaction forces, and vertical arm rest forces were collected during each trial. All data were time synchronised using a custom-designed LED, seat switch and master-slave computer system.

2.3. Data collection

2.3.1. Kinematic

Each subject was filmed (25 Hz) in the sagittal plane by a Panasonic S-VHS-C Movie camera. The camera was levelled, securely mounted on a tripod and positioned perpendicular to the chair. Before filming, nine fluorescent adhesive markers were attached to the skin on the right side of each subject’s body at the head of the fifth-metatarsal, calcaneous, lateral malleolus, lateral femoral condyle, greater trochanter, acromion process, lateral epicondyke of the humerus, ulnar styloid process, and the vertex (Fig. 1). A seat switch (5 V), comprised of wires threaded through the seat cushion and aluminium tape adhered to the posterior thighs of each subject, indicated when each subject had lost contact with the seat cushion of the Eser Ejector chair.

2.3.2. Kinetic

The vertical ($F_y$), anteroposterior ($F_x$) and mediolateral ($F_z$) ground reaction forces generated by each subject when rising were recorded (1000 Hz) using a calibrated Kistler multichannel force platform (type 9281B) (600 mm x 400 mm). The ejector chair was not in contact with the force platform and therefore did not contribute to the applied forces.

The vertical components of force exerted by each subject’s upper extremities through each arm rest of the chair were recorded using four calibrated S-shaped load cells (LC1205-K050). Two load cells were secured beneath each chair arm rest between two metal $25 \times 2 \times 570$ mm RH sections (Fig. 2). Two RH sections were welded to the arm rests, one on each side, and did not attach to any other part of the chair. The remaining two RH sections were welded to the legs of the chair. Therefore, each arm rest was not connected to any other part of the chair and was able to respond to loads exerted on them in isolation. Despite all the modifications made to the chair, the shape, height and external design of the arm rests were not altered in any way by the load cell system. The voltage from each arm rest’s load cell was fed through an AC/DC amplifier into a personal computer (MCT 486DX) via a PC-30D A-D card.

2.4. Data analysis

2.4.1. Kinematic

The video data were collected from the video recorder by an MCT 486DX-66 personal computer via a video grabber board (Creative Labs VideoSpigot) using the
Fig. 3. Link segment model for analyses with trunk angle ($\sigma_t$), knee angle ($\sigma_k$) and ankle angle ($\sigma_a$) shown.

VideoCap software package (Video for Windows 1.1). One representative trial per condition was analysed for each subject. The $x$ and $y$ coordinates of the nine markers which defined the anatomical link system and a reference marker were manually digitised in sequence (25 Hz) from five frames before the first notable movement of each subject’s head until five frames after an erect standing posture was attained. The digitised data were smoothed using a fourth-order low-pass butterworth digital filter (6 Hz) (Winter, 1990). Subsequently, time to rise, joint angles (Fig. 3), segmental angular displacements, and the velocity of the total body CoM were calculated at seat off. The total body CoM was calculated using individual subject anthropometric measures and proportionality data from Dempster (1955). All analyses were performed using PROG software (Andrews, 1997).

2.4.2. Net joint moments

The ground reaction forces were offset to zero, summed and scaled to obtain time histories of the ground reaction forces (N) generated in each of the three orthogonal directions. The centre of pressure of the applied force was then determined using these calculated forces and the algorithm specified by Bobbert and Schamhardt (1990). The centre of pressure data were combined with the kinematic and anthropometric data to calculate the joint reaction forces and joint moments of force (N m) about the ankle and knee using Newtonian equations of motion and an inverse dynamics approach, working progressively from the distal to proximal segment end (Winter, 1990). Net joint moments were obtained at seat off and were defined as positive for knee extension and ankle plantar flexion.

2.4.3. Chair arm rest impulses

Maximal vertical impulsive forces applied to the chair arm rests were calculated for 500 ms blocks for each load cell at seat off. The impulses from the four load cells beneath the arm rests were then summed to obtain the total vertical impulse (N s) applied to the arm rests during the STS transfer. Total vertical impulse for each condition was then normalised to body mass (N s kg$^{-1}$).

2.4.4. Statistical analysis

The kinematic and kinetic variables and subject estimations were analysed using a repeated measures two-way analysis of variance (ANOVA) design with two dependent variables (seat height and ejector mechanism). The purpose of this design was to determine whether seat height or use of the ejector mechanism significantly ($p < 0.05$) influenced STS transfer mechanics.

3. Results

3.1. Subject estimations

No significant differences were noted for the subjects’ RPE estimations during the STS transfer when rising from a high seat compared to a low seat. However, RPE estimates significantly decreased when using the ejector mechanism (mean = 8.9 ± 1.9) compared to no ejector mechanism use (mean = 10.5 ± 2.3; $F_{1,44} = 6.13; p = 0.017$). No significant differences were found in VAS estimates, regardless of seat height or ejector mechanism operation.

3.2. Time to rise

The total time required to perform the STS transfer ranged from 3.7 to 8.9 s. No significant differences were found for time to rise regardless of seat height or ejector mechanism use (Table 1). Seat off occurred significantly later when rising from a high seat (mean = 60.9%; $F_{1,44} = 10.18; p = 0.009$) and when using the ejector mechanism (mean = 62.4%; $F_{1,44} = 13.40; p = 0.004$) than when rising from a low seat (mean = 52.8%) or rising unassisted (mean = 51.3%).

3.3. Angular displacements

Values for kinematic variables calculated during the STS transfer at seat off are displayed in Table 1. When rising from a high seat, there was a significantly greater
trunk angle ($\sigma_t$), knee angle ($\sigma_k$) and ankle angle ($\sigma_a$) at seat off ($\sigma_t$: $F_{1,44} = 6.86; p = 0.024$; $\sigma_k$: $F_{1,44} = 20.28; p < 0.001$; $\sigma_a$: $F_{1,44} = 11.27; p = 0.006$, as well as increased ankle angular displacement ($F_{1,44} = 11.78; p = 0.006$) compared to rising from a low seat. However, knee angular displacement significantly decreased when rising from a high seat compared to a low seat ($F_{1,44} = 10.46; p = 0.008$). Trunk angular velocity significantly changed from a rapidly extending trunk motion when rising from a low seat to a slow flexing trunk motion when rising from a high seat ($F_{1,44} = 16.26; p = 0.002$).

When rising using the ejector mechanism, trunk and knee angular displacement significantly decreased compared to rising unassisted (trunk: $F_{1,44} = 19.97; p < 0.001$; knee: $F_{1,44} = 18.85; p = 0.001$). However, $\sigma_t$ and $\sigma_k$ at seat off significantly increased when rising using the ejector mechanism compared to no ejector mechanism use ($\sigma_t$: $F_{1,44} = 17.52; p = 0.002$; $\sigma_k$: $F_{1,44} = 67.30; p < 0.001$). Similar to seat height effects, trunk angular velocity significantly changed from a rapidly extending trunk motion when rising with ejector mechanism assistance to a slow flexing trunk motion when rising unassisted ($F_{1,44} = 19.92; p < 0.001$).

Two statistical interactions were found. The effect of the ejector mechanism on $\sigma_t$ was dependent upon seat height ($F_{1,44} = 15.71; p = 0.002$), such that $\sigma_t$ in the high seat with ejector mechanism condition was significantly greater than all other conditions. That is, there was the least amount of trunk flexion in the high seat with ejector mechanism condition. The same result was found for $\sigma_a$. Although there was a significant main effect for seat height, this was dependent upon ejector mechanism operation ($F_{1,44} = 9.55; p = 0.010$), such that during the low seat with the ejector mechanism operating, $\sigma_a$ was significantly less than all other conditions. That is, there was the greatest amount of ankle dorsiflexion during the low seat with ejector mechanism condition.

### 3.4. Mass centre of the body

Regardless of seat height or ejector mechanism use, there were no significant differences in the mean peak horizontal velocity of the subjects' total body CoM or the mean horizontal velocity of the total body CoM at seat off (Table 1). There was also no significant difference in the mean time to peak horizontal velocity of the total body CoM regardless of seat height or ejector mechanism use (Table 1).

### 3.5. Net knee and ankle moments

There were no significant differences in the mean net moments generated at the knee and ankle at seat off regardless of seat height (knee: $F_{1,44} = 2.74; p = 0.126$; ankle: $F_{1,44} = 2.46; p = 0.145$) or ejector mechanism use (knee: $F_{1,44} = 3.02; p = 0.110$; ankle: $F_{1,44} = 0.08; p = 0.787$) (Table 2).

### 3.6. Chair arm rest impulses

Both the net and normalised vertical impulses applied to the chair arm rests during the STS transfer significantly decreased when subjects performed the STS
transfer from a high seat (net: $F_{1,44} = 22.55; p < 0.001$; normalised: $F_{1,44} = 33.89; p < 0.001$) and when using the ejector mechanism (net: $F_{1,44} = 12.13; p < 0.005$; normalised: $F_{1,44} = 20.27; p = 0.002$) compared to rising from a low seat or rising unassisted (Table 2). There was also a significant interaction found (net: $F_{1,44} = 8.15; p = 0.016$; normalised: $F_{1,44} = 9.69; p = 0.01$), such that the low seat with no ejector condition provided vertical impulses that were significantly greater than all other conditions. That is, subjects applied the most force to the chair arm rests in the low seat with no ejector condition.

### 4. Discussion

#### 4.1. Subject estimations

Wretenberg, Arborelius et al. (1993) reported that subjects estimated rising from a spring loaded flap seat to be equally as easy as when rising from a standard seat. However, subject RPE estimates decreased when seat height was raised (Arborelius et al., 1992; Weiner et al., 1993). The present study found no differences in RPE estimates with increased seat height, but subjects reported significantly reduced RPE estimates when rising using the ejector mechanism. Therefore, subjects subjectively found it easier to perform the STS transfer when using the ejector mechanism as opposed to rising unassisted or merely raising seat height. The VAS estimates in the present study were very low with most values not exceeding 2 cm (maximum score = 10 cm) indicating subjects did not experience much pain when performing the STS transfer (Huskisson, 1974). Subjects in the present study may have become accustomed to pain levels associated with their RA and learned to perform the STS transfer in a way which would minimise the level of pain they sensed. Therefore, although not influencing pain levels, use of the ejector mechanism decreased the level of exertion during STS transfers performed by elderly female RA patients in the present study. These decreases were not evident when changing seat height.

#### 4.2. Time to rise

Total rising times in the present study were longer than those typically reported for elderly subjects (Alexander et al., 1991; Bashford et al., 1994; Ikeda et al., 1991) and did not significantly change regardless of seat height or ejector mechanism use. Bashford et al. (1994) reported that owners and regular users of ejector chairs took less time to rise when rising using the ejector mechanism compared to rising unassisted. However, subjects in the present study were novel ejector chair users and, although familiarised with the ejector chair, may not have been fully comfortable or confident with the spring action of the seat cushion. When comparing temporal characteristics of the different chair rising conditions in the present study, the only difference found was that subjects left the seat cushion significantly later when rising from a high seat or using the ejector mechanism compared to rising from a low seat or rising unassisted. However, seat off times in the present study were later in all conditions compared to seat off times reported by Roebroek et al. (1994). A later seat off time may have indicated subjects required more time to reposition themselves prior to rising (Hughes et al., 1994) and/or stayed in contact with the seat cushion for longer to enhance stability throughout the STS transfer.

#### 4.3. Angular displacements

The values of $\sigma_s$, $\sigma_k$, and $\sigma_a$ at seat off reported in the present study were similar to those typically displayed by older subjects when rising from a standard chair (Alexander et al., 1991; Ikeda et al., 1991; Millington et al., 1992; Wheeler et al., 1985). However, when rising from a high seat or using the ejector mechanism, $\sigma_s$, $\sigma_k$ and $\sigma_a$ in the present study significantly increased. That is, there was decreased trunk and knee flexion and decreased ankle dorsiflexion, compared to rising from a low seat or rising unassisted. Therefore, at seat off, subjects were in a more extended position when rising from a high seat or using the ejector mechanism compared to rising from a low
seat or rising unassisted. When upright, the total body CoM does not need to be translated as far during the rising process before it falls within the base of support (the feet) at terminal stance. Therefore, subjects may have been more stable throughout the STS transfer when rising from a high seat or using the ejector mechanism.

Post hoc analysis of the trunk flexion data indicated that the high seat with ejector assistance condition required the least amount of trunk flexion when compared to the other three conditions. Decreased trunk flexion may have indicated that subjects required less momentum to be developed in the upper body to translate the body forwards and upwards when rising (Hughes et al., 1994; Schenkman et al., 1990). Decreased trunk flexion may also have indicated that subjects did not have to move their CoM as far forwards to develop dynamic stability before rising (Hughes et al., 1994; Schenkman et al., 1990). In both cases, or when using different rising strategies, the individual would be more stable throughout the STS transfer, relying on the seat cushion to provide the forwards and upwards force to assist rising (Hughes et al., 1994). The significantly decreased trunk angular displacement found in the present study may also have indicated that subjects were more stable and upright throughout the STS transfer when rising using the ejector mechanism.

Ankle angular displacement was found to increase with a high seat. This finding was in opposition to the findings of Burdett et al. (1985), but can be explained, in that, some subjects in the present study were unable to touch the floor with their feet when sitting on the high seat. However, similar to the results of Burdett et al. (1985) knee angular displacement decreased as seat height increased. Knee angular displacement, but not ankle angular displacement, also decreased with ejector mechanism use. RA patients may have a decreased range of motion available at the knee compared to healthy elderly subjects due to muscle weakness and joint pain. Therefore, the requirement of less knee angular displacement to rise may be beneficial for these patients.

4.4. Mass centre of the body

A major concern expressed when prescribing ejector chairs is that the chair may impart a large horizontal destabilising force to the user at seat off, predisposing them to falls. At initiation of the STS movement, the vertical force component of a flap seat has been shown to dominate, with the horizontal force component being larger than the vertical force component at completion of the STS transfer (Wretenberg et al., 1993). This observation, combined with the fact that the subject’s CoM at seat off is further forward, may make elderly and disabled people lose balance and fall when using flap seats (Wretenberg et al., 1993). In the present study, neither the magnitude of the mean-peak horizontal velocity of the CoM, nor the mean-peak horizontal velocity of the CoM at seat off, increased when rising using the ejector mechanism compared to rising unassisted. Furthermore, timing of the mean-peak horizontal velocity in each seat condition did not change and was similar to those reported by Roebroeck et al. (1994). Subjects also did not subjectively report feeling unstable when rising with the assistance of the ejector mechanism. Therefore, ejector mechanism use did not appear to destabilise the subjects in the present study.

4.5. Net knee and ankle moments

Moments acting about the knee have been reported to decrease as seat height increases (Burdett et al., 1985; Rodosky et al., 1989; Roebroeck et al., 1994; Wretenberg et al., 1993). Wretenberg et al. (1993) found the mean peak knee moments for eight osteoarthritic patients when rising using a flap seat significantly decreased ($p < 0.001$) from 57.2 to 33.0 Nm when rising from a standard chair. The authors concluded the reduced moments made the STS transfer task easier for patients and helped to prevent further destruction of the osteoarthritic joints. However, these studies have reported peak knee and ankle moments. In the present study, only net knee and ankle moments at seat off were presented as it is suggested that seat off is the most stressful time in the STS transfer and it provided a common event in the STS transfer which was comparable between subjects (Kralj et al., 1990; Schenkman et al., 1990).

Regardless of seat height or ejector mechanism use, knee and ankle moments in the present study did not change at seat off. Furthermore, net ankle moments at seat off reported in the present study were consistent with the peak net ankle moments reported in the literature (Arborelius et al., 1992; Burdett et al., 1985; Rodosky et al., 1989; Roebroeck et al., 1994; Wretenberg, Arborelius, et al., 1993). However, the present net knee moments at seat off were relatively low compared with the peak net knee moments reported in the literature (Arborelius et al., 1992; Burdett et al., 1985; Rodosky et al., 1989; Roebroeck et al., 1994; Wretenberg et al., 1993). Therefore, the RA patients may have used transfer strategies which lowered the moments required at the knee in an attempt to protect their joints against high loading forces, although it is acknowledged that low net moments are not always synonymous with low loading joint forces. Therefore, further research is required to examine joint loading forces when rising from the ejector chair.

4.6. Chair arm rest forces

Elderly subjects unable to rise without chair arm rest assistance have been found to increase the amount of force they applied to the chair arm rests compared to
elderly subjects able to rise unassisted (Alexander et al., 1991). Use of the upper extremities are thought to compensate for lower extremity strength deficits by providing propulsive forces when rising, as well playing a major role in stabilising the body (Carr, 1992; Hoy and Marcus, 1992). An important finding in the present study was that less force was required to be applied to the chair arm rests when rising from a high seat or using the ejector mechanism compared to rising from a low seat or rising unassisted. However, rising from a low seat unassisted required by far the greatest forces to be applied to the chair arm rests compared to any other condition (Fig. 4). Therefore, when rising from a high seat or using the ejector mechanism, the role of the upper extremities was predominantly to stabilise the body throughout the STS transfer rather than to assist rising. Reduced arm rest forces, or reduced reliance on the upper extremities when rising is important in terms of selecting a chair suitable for use by individuals who not only have lower extremity weaknesses, but also upper extremity complications, particularly those associated with RA. The high variation evident in the chair arm rest data (Fig. 4) may reflect subjects using the chair arm rests in a variety of compensatory techniques when performing the STS transfer (Alexander et al., 1991).

4.7. Chair selection considerations

When attempting to select a chair suitable for older RA patients, it would appear that based on the present results both a high seat and ejector mechanism use facilitated rising. Therefore, both increased seat height and use of an ejector chair may benefit elderly individuals with RA who have pain, weakness, and disability in both the upper and lower extremity joints. However, with a chair that has a seat height higher than the shank a footstool is necessary (Burdett et al., 1985). A footstool reduces pressure on the nerves and blood vessels passing posterior to the knees and reduces stresses in the ligaments crossing the knee joint by allowing the foot to share some of the lower extremities weight (Burdett et al., 1985). However, a footstool placed in front of the chair may become an obstacle that could contribute to a fall. Therefore, ejector chairs, which can be used at a low-seat height, appear more appropriate aids to assist STS transfers than a high seat, particularly for elderly individuals who are prone to falling and with both upper and lower extremity weakness and/or pathology. An ejector chair would be especially appropriate when further increases in seat height or upper extremity use no longer provide adequate assistance to complete STS transfers. Ejector chairs were also subjectively perceived to be easier to rise from compared to a high or low seat with no ejector mechanism use.

5. Conclusions

Based on the present findings, it was concluded that increased seat height and use of an ejector mechanism both facilitated rising during STS transfers performed by elderly female RA patients. However, using the ejector chair may be preferred by these patients compared to merely raising seat height because it does not necessitate the use of a footstool, a possible obstacle contributing to falls. Despite potential benefits in assisting these patients to rise, there exists concerns that use of mechanical ejector devices may cause accelerated muscle degeneration due to muscle disuse. Also, no research was located which has established the level of assistive force required to facilitate individual rising during the STS transfer. A level of force too strong could be dangerous to the user and too weak may not assist rising as required. Therefore, future research is required to determine the appropriate force level for assistance, as well as whether habitual ejector chair use contributes to excessive muscle deconditioning.

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