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BIOMECHANICAL ANALYSES OF RISING FROM A CHAIR

ALBERT B. SCHULTZ,*† NEIL B. ALEXANDER‡ and JAMES A. ASHTON-MILLER*

*Department of Mechanical Engineering and Applied Mechanics, †Institute of Gerontology and ‡Division of Geriatric Medicine and GRECC-VA Medical Center, University of Michigan, Ann Arbor, MI 48109-2125, U.S.A

Abstract—Quantification of the biomechanical factors that underlie the inability to rise from a chair can help explain why this disability occurs and can aid in the design of chairs and of therapeutic intervention programs. Experimental data collected earlier from 17 young adult and two groups of elderly subjects, 23 healthy and 11 impaired, rising from a standard chair under controlled conditions were analyzed using a planar biomechanical model. The joint torque strength requirements and the location of the floor reaction force at liftoff from the seat in the different groups and under several conditions were calculated. Analyses were also made of how body configurations and the use of hand force affect these joint torques and reaction locations.

In all three groups, the required torques at liftoff were modest compared to literature data on voluntary strengths. Among the three groups rising with the use of hands, at the time of liftoff from the seat, the impaired old subjects, on an average, placed the reaction force the most anterior, the healthy old subjects placed it intermediately and the young subjects placed it the least anterior, within the foot support area. Moreover, the results suggest that, at liftoff, all subjects placed more importance on locating the floor reaction force to achieve acceptable postural stability than on diminishing the magnitudes of the needed joint muscle strengths.

INTRODUCTION

More than two million persons older than 64 years in the United States alone have difficulty in rising from a chair (Dawson *et al.*, 1987). Inability to rise independently often contributes to institutionalization. Rising from a chair requires that adequate torques be developed about each of the body's joints and that, at least in slowly performed rises, the location of the vertical component of the floor support force at liftoff from the seat be brought to within the area of the foot support. Comparisons of the maximum joint torques that an individual can develop with the torques needed to rise, and analyses of his placement of the support force location can provide insights into the biomechanical determinants of the ability to rise from a chair. This understanding can, in turn, be used to determine the sources of inability to rise, to design more suitable chairs, and to devise more effective therapeutic intervention programs.

Many studies concerned with chair rise biomechanics have been reported. These include observations, during a rise, of body kinematics (Jones *et al.*, 1962; Kelley *et al.*, 1976; Ellis *et al.*, 1979, 1985; Bajd *et al.*, 1982; Nemeth *et al.*, 1984; Burdett *et al.*, 1985; Wheeler *et al.*, 1985; Nuzik *et al.*, 1986; Fleckenstein *et al.*, 1988; Stevens *et al.*, 1989; Rodosky *et al.*, 1989; Jeng *et al.*, 1990; Kralj *et al.*, 1990; Schenkman *et al.*, 1990; Riley *et al.*, 1991), foot/floor reaction forces (Ellis *et al.*, 1979, 1985; Bajd *et al.*, 1982; Nemeth *et al.*, 1984; Burdett *et al.*, 1985; Stevens *et al.*, 1989; Rodosky *et al.*, 1989; Seedhom *et al.*, 1976; Yoshida *et al.*, 1985), myoelectric activities (Kelley *et al.*, 1976; Munton *et al.*, 1984; Nemeth *et al.*, 1984; Wheeler *et al.*, 1985; Ellis *et al.*, 1985; Stevens *et al.*, 1989), and biomechanical model analyses (Kelley *et al.*, 1976; Seedhom *et al.*, 1976; Ellis *et al.*, 1979, 1985; Bajd *et al.*, 1982; Nemeth *et al.*, 1984; Burdett *et al.*, 1985; Fleckenstein *et al.*, 1988; Rodosky *et al.*, 1989; Ikeda *et al.*, 1991; Pai and Rogers, 1990, 1991). Nevertheless, no comprehensive analyses of what factors affect the joint torques and floor reaction locations or of why chair rise strategies might differ between young and elderly adults seem available.

In the present study, experimental data collected earlier from young adult and two groups of elderly subjects, one healthy and one impaired, rising from a standard chair under controlled conditions were analyzed using a planar biomechanical model. The analyses addressed the following questions:

(1) What individual body segment movements are most effective in helping to bring the floor reaction location to its required location within the area of the foot support?

(2) Were there notable subject age and impairment group differences in the location of the floor reaction at liftoff?

(3) What joint torques were used in rising?

(4) Were there notable subject age and impairment group differences in the torques used?

(5) How did the torques used compare with literature data on maximum torque strengths?

(6) What might explain the different choices for mean body configurations and hand force use at liftoff among the age and impairment groups?

To keep the analyses relatively simple, only slowly performed, sagittally symmetric rises from carefully

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Address correspondence to: Albert B. Schultz, Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI 48109-2125, U.S.A.

Table 1. Mean Phase 1 body segment rotation data* (°) used in analyses

	With hand use			Without hand use		
Group	Leg	Thigh	Upper body	Leg	Thigh	Upper body
Young	4.6	10.5	32.8	5.9	11.2	37.2
Old able	6.3	15.7	33.2	8.2	15.7	42.9
Old unable	8.1	11.0	42.4			

Positive entries correspond to rotations in leg flexion, thigh extension and upper-body flexion.

*Data from Alexander *et al.* (1991).

controlled initial conditions were studied. Conditions primarily at the time of liftoff from the seat support were analyzed.

METHODS

Configuration and hand force experimental data analyzed

A companion paper (Alexander *et al.*, 1991) reports biomechanical measurements of chair rise performances made in three subject groups. Two of the groups consisted of 17 healthy young adults (young group) and 23 healthy elderly adults (old able group), all of whom were able to rise both with and without the use of hands from an instrumented laboratory chair under controlled initial conditions. The third group consisted of another 11 elderly females who were unable to rise under the standard conditions investigated without the use of hands, but could rise when hand use was allowed (old unable group). Body segment motions during sagittally symmetric chair rises were divided into two phases. In Phase 1, body segment movements were essentially anterior. In Phase 2 they were essentially vertical. Liftoff from the seat occurred approximately at the end of Phase 1. The data of Alexander *et al.* (Table 1) were used to define the Phase 1 end configurations that were analyzed with the model. Their data on mean measured peak hand forces (Table 2) were used in studies concerning the effects of hand force use. It was assumed for the present studies that the peak horizontal and vertical forces occurred at the end of Phase 1, since Alexander *et al.* found this to be approximately correct.

Biomechanical model

The biomechanical model used for all analyses consisted of 10 linked rigid bodies; one each to represent the feet, lower legs, thighs, pelvis, lower trunk, upper trunk, head and neck, upper arms, forearms, and hands (Fig. 1). All the links were assumed to move only in the sagittal plane. Each link was assigned a length, a mass center location and a mass scaled to each subject's height and weight from standard an-

Table 2. Mean peak hand force data* used in analyses

Group	Total† horizontal (N)	Total† vertical (N)	Resultant force (N)	Force angle‡ (°)
Young	106	84	154	51.5
Old able	98	94	144	49.1
Old unable	129	82	159	56.9

*Data from Alexander *et al.* (1991).

†Sums over two hands. Forces are those exerted by the handles on the hands.

‡Measured counterclockwise from the anterior horizontal direction.

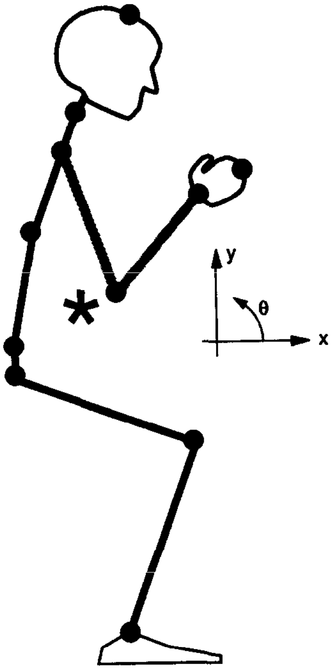

Fig. 1. Schematic diagram of the 10-rigid-link biomechanical model used to calculate the net joint torques and the total body mass center and vertical floor reaction locations. If hand forces are not used to assist the rise, the vertical floor reaction force will lie directly inferior to the location of the total body mass center, which is shown by the asterisk.

Table 3. Anthropometric data (%) incorporated in the biomechanical model

Link masses, lengths and center of mass (CM) locations when standing with arms overhead

	Mass of link	Height of CM	Length of link	Distance inferior joint to CM
Feet	3.4	1.8	3.9	1.8
Lower legs	9.6	18.2	24.6	14.3
Upper legs	21.5	42.5	23.7	14.0
Pelvis	9.3	54.1	4.2	2.0
Lower trunk	18.4	63.1	14.0	6.8
Upper trunk	17.4	76.9	15.9	6.6
Head/neck	7.9	92.5	13.8	6.3
Upper arms	6.6	90.6	18.9	9.4
Lower arms	4.2	106.9	16.0	6.8
Hands	1.7	119.2	6.2	3.1
Total	100.0			

Heights of joint centers when standing with arms overhead

Ankles	3.9
Knees	28.4
Hips	52.1
L5/S1	56.3
T10	70.3
C4	86.2
Top of head	100.0
Shoulders	81.2
Elbows	100.1
Wrists	116.1
Tip of hands	122.3

Masses are given as percentage of the total body mass and distances as percentage of the total standing height. Data adapted from *Anthropometric Source Book* (1978).

thropometric data (*Anthropometric Source Book*, 1978) (Table 3).

Sets of the 10 angles that these links subtended at the horizontal were prescribed. Using these angles and the anthropometric data, the locations of the ankle, knee, hip, L5/S1 intervertebral, T9/T10 intervertebral, shoulder, elbow, wrist, and C3/C4 intervertebral joints were calculated. The locations of the mass centers of each of the body segments were also calculated, and from these, the location of the total body mass center.

The horizontal and the vertical net reaction forces and the net reaction sagittal plane moment at each joint were then computed from the equations of equilibrium, using the segment weight and external-force data while assuming inertial loads to be negligible. Proceeding inferiorly, link by link, from the head and hands, ultimately the net reaction at the foot/floor interface was computed, yielding the anteroposterior location of the floor reaction relative to the ankle joints. When no external forces were exerted on the hands, this reaction location lay directly below the total body mass center. Only the group means of the floor reaction location and the net reaction moments at the ankles, knees, hips and shoulders will be reported here. Student's t-tests were made to determine the significance of age group and hand use differences in these means.

Situations examined

Four sets of biomechanical model analyses of the required joint torques and floor reaction locations were made. In all but Set 1, the reaction locations and the net joint torques at the end of Phase 1 were calculated.

The Set 1 analyses considered hypothetical body segment movements to explore which segment movements contribute most to the achievement of the biomechanical requirements for rising. An initial-state calculation determined what the reaction location and the joint torques need to be in the hypothetical absence of seat and hand support forces. In this initial state, the thighs were horizontal and all the other body segments were vertical, with the arms and hands hanging down (Fig. 2). The movements examined were stretching the arms and hands anteriorly, flexing the head and upper neck by 45° and 20° rotations, in turn, of leg flexion, of thigh extension and of flexion of the trunk, arms and head.

The Set 2 and Set 3 analyses considered the mean observed configurations at liftoff from the seat in the two subject groups rising without and the three groups rising with the use of hands, respectively. The Set 4 analyses considered the mean observed configuration at liftoff from the seat in the old able group rising with the use of hands, but incorporated hypothetical hand forces to explore the effects of hand force use on floor reaction locations and the needed torques.

Set 3 and Set 4 calculations were made in two ways. First, the shoulders, elbows, wrists and hands were assumed to lie in a sagittal plane [Fig. 3(a)]. Second, they were assumed to lie in the plane defined by a line joining the shoulders and hands and a transverse line [Fig. 3(b)]. In other words, the upper arms were abducted in the first set of calculations and maximally abducted in the second set, but hand and shoulder locations were the same in both the sets. The results from these two arm segment placements probably encompass the results that would have been obtained had the actual three-dimensional configurations of the arms been used. The actual location of the mass center of the upper extremities would lie somewhere between the mass center locations for these two arm segment placements. The mean values over these two arm configuration sets were used in further analyses.

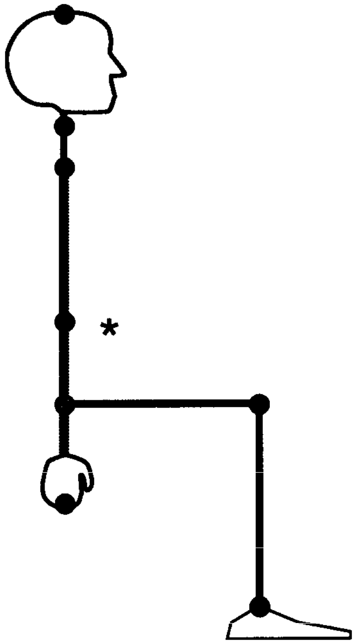

Fig. 2. Schematic diagram of the initial state used in the Set 1 analyses. The location of the total body mass center is shown by the asterisk.

RESULTS

Effects of hypothetical segment movements (Set 1 analyses)

People fall when a chair is pulled out from under them in a fully upright initial configuration because, in the absence of hand and seat support, the required floor reaction location for 50th percentile male anthropometry, for example, lies 33 cm posterior to the ankles (Table 4), or well outside the area of the foot/floor contact. Assuming that the heels are 8 cm posterior to the ankle joints, a slow rise can be achieved only after the reaction location is brought 25 cm forwards so as to have it anterior to the heels.

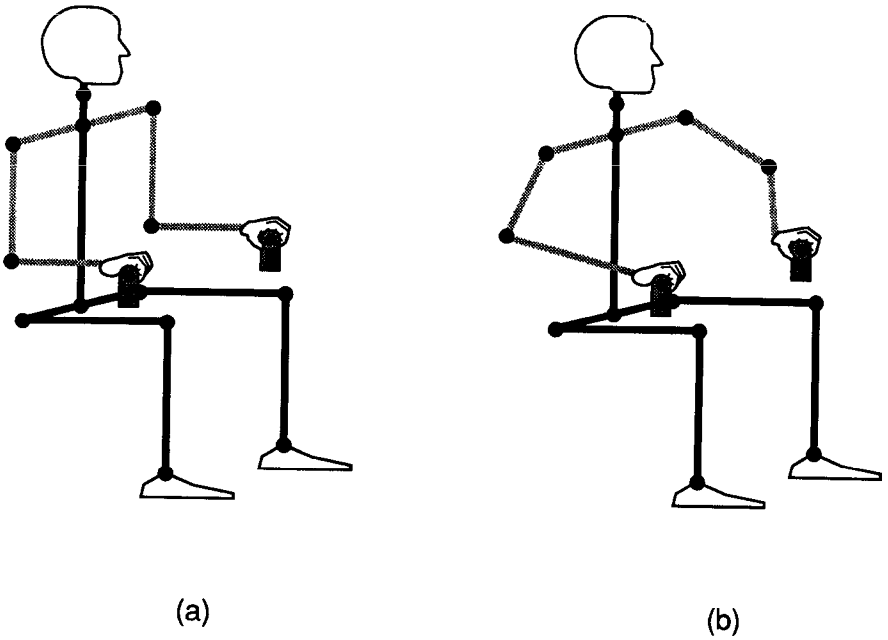

Fig. 3. Schematic diagram showing the two placements of the arms used in the Set 3 and Set 4 analyses. In each set, one analysis was made in which the shoulders, elbows and hands all lay in a sagittal plane (a). A second analysis was made in which the upper arms were maximally abducted (b). The locations of the shoulders and hands were the same in both analyses.

Table 4. Effects of hypothetical segment movements on reaction locations and joint torques

	Floor Reaction Location* (cm)	Required joint torques† (N m)			
		Ankle	Knee	Hip	Shoulder
Initial configuration‡	−33.0	226	226	0	0
Stretch arms forward	−28.8	198	198	29	29
Flex head 45°	−32.4	222	222	4	0
Flex legs 20°	−19.1	131	226	0	0
Extend thighs 20°	−31.0	213	213	0	0
Flex upper body 20°	−24.9	171	171	56	0

*Anterior of ankle joints.

†Total for two joints. Positive entries correspond to ankle plantarflexion, knee extension, hip extension and shoulder flexion.

‡Thighs horizontal, arms down, all other segments vertical. Seat and hand support forces were assumed to be zero for this calculation.

Moving body segments anteriorly helps to do this, but flexing the head and neck 45° moves the reaction location only by 0.6 cm, bringing it to 32.4 cm posterior of the ankles. Extending the arms moves the reaction location by 4.2 cm, bringing it to 28.8 cm posterior of the ankles. The effects of the 20° segment rotations studied show that also thigh extension by itself has little effect. Upper-body flexion moves the reaction forward by 8.1 cm, bringing it to 24.9 cm posterior of the ankles. The most effective 20° body segment rotation is a flexion of the legs. This amount of leg flexion moves the reaction forward by 13.9 cm of the required 25 cm. The effects of these hypothetical segment movements on the required joint torques were variable (Table 4).

Thus, in answer to question (1), flexing the lower legs to bring the feet under the upper body segments is perhaps the most effective maneuver to facilitate rising from a chair. Forward flexion of body segments superior to the hips is also effective.

Reaction locations (Set 2 and Set 3 analyses)

In answer to question (2), both the young and the old able groups who rose without the use of hands brought the floor reaction at liftoff close to the ankles (Table 5). The mean location in the young subjects was 1.5 cm posterior of the ankles, while in the old able subjects it was 1.9 cm anterior of the ankles. The old able subjects achieved this by using larger segment rotations at liftoff (Alexander *et al.*, 1991).

All three subject groups when rising with the use of hands brought the floor reaction at liftoff anterior to the ankles (Table 5). Both the young and the old able groups brought the floor reaction further anterior when they rose using their hands compared to when they rose without hand use (Table 5). Moreover, when using hands, the old unable group placed the floor reaction the most anterior (10.7 cm) to the ankles, the old able group placed it intermediately (7.1 cm) and the young group placed it the least anterior (4.4 cm) to the ankles.

Required torques (Set 2 and Set 3 analyses)

With regard to question (3), the model-calculated joint torques required at liftoff from the seat when rising either without or with hand use (Table 5 provides both absolute torques and torques expressed as a percentage of the product of body weight and height) showed that ankle plantarflexor strengths needed were at most 39 N m. The required knee extensor and hip extensor torques were at most 119 and 96 N m, respectively, and the required shoulder flexor torques were at most 37 N m.

When rising without the use of hands, both groups reduced substantially the ankle and knee torques needed at liftoff compared to those needed in unsupported initial configurations, but at the expense of requiring small shoulder flexor and moderate hip extensor torques (Tables 4 and 5).

Hand use increased the mean ankle and shoulder torques from their no-hand-use values in the two groups who could also rise without the use of hands, young and old able. However, hand use decreased the required hip and knee torques from no-hand-use values by up to 35 N m (Table 5).

In answer to question (4), with or without hand use, the old able subjects did not choose to reduce the required joint torques appreciably compared to those of the young subjects. The old unable group rising using hands, compared to the two more able groups, opted for marked reductions in the required joint torques at the knees and shoulders, but not at the ankles and hips.

Use of hand forces (Set 4 analyses)

The three subject groups, when rising with the use of hands, developed a three-group-mean resultant hand

Table 5. Mean reaction locations and joint torques at liftoff from seat

	Floor reaction location	Required joint torques** Absolute (N m)				Required joint torques** Percent of body weight × height			
Group	(cm)*	Ankle	Knee	Hip	Shoulder	Ankle	Knee	Hip	Shoulder
Without the use of hands									
Young	−1.5 (3.2)	−8 (21)	119 (20)	82 (24)	8 (2)	−0.87	10.82	7.31	0.68
Old able	1.9 (2.9)‡	14 (22)†	112 (32)	96 (32)	9 (3)	1.12	9.62	8.15	0.75
With the use of hands									
Young	4.4 (5.9)*§	21 (33)*‡	99 (20)§	53 (19)¶	32 (25)*¶	1.77	8.96	4.75	2.88
Old able	7.1 (6.9)*§	36 (41)*†	99 (33)	61 (25)¶	37 (34)*¶	3.10	8.45	5.25	3.15
Old unable	10.7 (6.1)	39 (19)	54 (15)***	46 (20)	17 (26)	4.83	6.42	5.54	2.06

Standard deviations in parentheses.

*Anterior of ankle joints.

**Total for two joints. Positive entries correspond to ankle plantarflexion, knee extension, hip extension and shoulder flexion.

***Old unable < Old able, $p < 0.001$.

†Old able > Young, $p < 0.005$.

‡Old able > Young, $p < 0.002$.

§With hands < without hands, $p < 0.01$.

¶With hands < without hands, $p < 0.001$.

*†With hands > without hands, $p < 0.05$.

*‡With hands > without hands, $p < 0.01$.

*§With hands > without hands, $p < 0.002$.

*¶With hands > without hands, $p < 0.001$.

Table 6. Effects of the use of hypothetical hand forces at liftoff on reaction locations and joint torques

	Floor Reaction Location*	Required joint torques† (N m)			
	(cm)	Ankle	Knee	Hip	Shoulder
Force (N) exerted at 50° angle					
120	5.5	27	108	64	33
130	6.2	31	106	62	35
140	6.9	34	104	60	37
150	7.7	37	102	59	39
160	8.4	40	99	57	42
170	9.2	44	97	56	44
180	10.0	47	95	54	46
Angle (°) of exertion of 150 N force					
35	10.5	55	100	69	49
40	9.7	49	100	65	46
45	8.7	43	101	62	43
50	7.7	37	102	59	39
55	6.4	30	103	56	36
60	5.1	23	104	53	32
65	3.7	16	106	50	28

* Anterior of ankle joints.

† Total for two joints. Positive entries correspond to ankle plantarflexion, knee extension, hip extension and shoulder flexion. The configuration analyzed was the Phase 1 end mean configuration of the old able group rising with the use of hands.

force on the armrests at liftoff of approximately 150 N at an angle of approximately 50° with respect to the horizontal. Table 6 shows the effects of hypothetical variations in both this push magnitude and direction, as calculated in the Set 4 analyses.

The floor reaction location moves anteriorly if the hand push magnitude is increased and moves posteriorly if the push direction is made more vertical. The use of larger push magnitudes has mixed effects on torques, increasing the required ankle and shoulder torques and slightly decreasing the required knee and hip torques. In contrast, the use of a more vertical push direction increases the required knee torques only slightly while substantially decreasing the required ankle, hip and shoulder torques.

DISCUSSION

Assumptions made in the analyses

The model analyses assumed that inertial loads were negligible. This assumption seems reasonable in old subjects who tend to rise from a chair slowly, but inertial loads may not be negligible when subjects rise from a chair rapidly. The importance of dynamics in chair rises has not yet been studied comprehensively, and this needs to be done. Ikeda *et al.* (1991) recently reported some data on this topic.

The model analyses were two-dimensional. This seems reasonable in that the subjects studied by Alexander *et al.* (1991) did rise in an essentially sagittally symmetric manner.

Significance of conditions as liftoff

The results presented here consider mainly floor reaction location and joint torque requirements at the instant of liftoff from the seat. Floor reaction location is of interest because, once liftoff occurs and the hand support is not available, it is a measure of postural stability. The stability is maximum when the floor reaction is centered between the heels and the toes. Prior to liftoff, the support of the seat provides ample postural stability and the reaction location is not of particular interest. After liftoff, the body segments are moved into their upright standing configuration in which postural stability is relatively easier to achieve. Thus, postural stability seems most threatened just when liftoff from the seat occurs.

Similarly, prior to liftoff, the hand and seat support forces keep joint torque requirements small. Joint torque requirements also become quite small once upright standing configurations are achieved. It is not yet known whether joint torque requirements are maximum at liftoff, but Ikeda *et al.* (1991) report that knee and hip torques reach maximum values either at liftoff or shortly thereafter. For these reasons, this study examined primarily the conditions at liftoff.

Required liftoff torques and voluntary strengths

Comparisons of joint torque requirements with joint torque strengths show the extent to which the inability to rise from a chair might result from a decline in the muscular strength. In answer to question (5), the model-calculated ankle, knee, hip and shoulder torques required at liftoff from the seat when rising with or without hand use (Table 5), when compared to literature data on maximum voluntary joint torque strengths (Table 7), were well below the strengths reported, even for subjects over 80 years old and even given the variability usually found in reports of voluntary strength studies. Only Whipple *et al.* (1987),

Table 7. Literature values for joint torque strengths (N m)*

Data source	Young adult† Females	Young adult† Males	Old‡ Females	Old‡ Males
Ankle dorsiflexors				
Oberg *et al.* (1987)	98			
Sepic *et al.* (1986)	88	156	92	148
Whipple *et al.* (1987) fallers§				2
Whipple *et al.* (1987) controls§				8
Ankle plantarflexors				
Oberg *et al.* (1987)	376			
Gerdle and Fugl-Meyer (1985)			156	278
Falkel (1978)	116	174		
Sepic *et al.* (1986)	200	258	164	262
Whipple *et al.* (1987) fallers§				11
Whipple *et al.* (1987) controls§				32
Knee flexors				
Knapic *et al.* (1983)	174	290		
Borges (1989)	200	310	130	218
Murray *et al.* (1985a)	156		100	
Whipple *et al.* (1987) fallers§				30
Whipple *et al.* (1987) controls§				62
Knee extensors				
Knapic *et al.* (1983)	320	500		
Dannenskiold *et al.* (1984)		150	240	
Aniansson *et al.* (1980)			216	382
Borges (1989)	366	578	256	376
Murray *et al.* (1985a)	352		220	
Whipple *et al.* (1987) fallers§				52
Whipple *et al.* (1987) controls§				90
Hip flexors				
Markhede and Grimby (1980)		240		
Cahalan *et al.* (1989)	132	216	102	178
Hip extensors				
Markhede and Grimby (1980)		496		
Cahalan *et al.* (1989)	252	408	220	406
Shoulder flexors				
Murray *et al.* (1985b)	100	208	76	168
Shoulder extensors				
Murray *et al.* (1985b)	106	160	70	148

* Most values quoted are for isometric strengths, but a few are for low-rate isokinetic strengths. Strengths have been doubled in order to compare them with the two-sides values calculated by the model.

† Mean age approximately 25–30 yr, see references.

‡ Mean age approximately 60–80 yr, see references.

§ These were nursing-home residents. Strengths were measured isokinetically.

in a group of elderly nursing-home residents tested isokinetically at 60° s^{-1}, found ankle plantarflexor strengths summed over left and right sides to be smaller than 39 N m or knee extensor strengths to be smaller than 119 N m. It appears from these comparisons that, with the possible exception of people who are very frail or who have substantial joint pain, joint torque requirements may not be a major factor limiting the ability to lift off from a chair.

To some degree, these comparisons of the required and the reported strengths might be questioned because the reported strengths were not always measured in body configurations approximating those used at seat liftoff. On the other hand, some reports show that joint torque strengths do not differ substantially at different joint angles (Knapic *et al.*, 1983; Murray *et al.*, 1985; Cahalan *et al.*, 1989, for example). Moreover, the evidence presented here from the Set 4 analyses that subjects do not opt for minimum joint torque requirements also suggests that, generally, the required joint torques are notably smaller than the available joint torques.

All earlier reports of chair rise biomechanics seem to consider torque requirements only at the ankles, knees and hips. The present analyses considered upper-extremity torque requirements as well, although only shoulder torque requirements have been reported here. Shoulder torque requirements were usually not large, but the largest mean value computed (37 N m) begins to approach maximum voluntary strengths for old females (70 N m). These data suggest that at least some frail people may be limited in chair rise performances by inadequate upper-extremity strengths.

Postural stability at liftoff

The analyses presented here of the data reported by Alexander *et al.* (1991) suggest that subjects, at liftoff from the seat, may place a higher priority on achieving postural stability through placement of the floor reaction location than on reducing joint torque requirements. Moreover, old adults, including those with no apparent difficulty in rising, seem to place a higher priority on this stability than do young adults. The reasons underlying these conclusions follow.

Alexander *et al.* found that, when rising without the use of hands, old subjects rotated their upper body segments, thighs and legs significantly more than did young adult subjects. The biomechanical model analyses show (Table 5) that these age group segment rotation differences led to only modest differences in the joint torques needed at liftoff, but the larger segment rotations resulted in a more anterior floor reaction location. Presumably, they choose this more anterior location because of an increased concern over falling backwards.

When rising with the use of hands, a similar preference for reaction location placement over torque reduction seemed to exist (Table 5). The torque requirements for the old groups differed little from those for the young. Only the knee torques required by the old unable group were significantly smaller than those of the other two groups. In contrast, there were clear group differences in floor reaction locations at liftoff. The old unable group placed the floor reaction the most anterior, the old able group placed it intermediately and young group placed it the least anterior.

Perhaps the most convincing argument that, at liftoff, more premium is placed on stability than on strength requirements comes from the Set 4 analyses of the effects of changing the hand force direction. These analyses showed (Table 6) that exerting hand forces more in a vertical and less in a horizontal direction reduces three of the four major joint torques while leaving the fourth essentially unchanged. Despite this, all three subject groups whose data were analyzed chose not to push as vertically as they might have. The cost of pushing more vertically is to move the floor reaction location backwards. The three groups chose instead (Table 5) to have the floor reaction 4–11 cm anterior of the ankles, although other choices could have reduced the torque requirements. The heels lie approximately 8 cm posterior, and the toes approximately 20 cm anterior of the ankles. The floor reaction locations selected by these groups were well within these limits for postural stability at liftoff.

Use of the hands to assist a rise is clearly helpful, since some subjects cannot rise without their use. But, contrary to our expectations, our results suggest that hands may not be used to reduce joint torque requirements, at least at liftoff. Rather, at liftoff, they may be used to gain increased postural stability.

Thus, in answer to question (6), our analyses suggest that, in their choices of body configuration and hand force use at liftoff from the seat support, all subject groups placed more importance on locating the floor reaction force to achieve acceptable postural stability than they did on reducing joint muscle strength requirements. The strategies chosen for rising provided the old unable group with the most stability, the old able with less, and the young group with the least.

If the achievement of postural stability at liftoff is indeed a major determinant of the ability to rise from a chair, there probably are ways to enhance this achievement. Better anteroposterior stability can be secured by getting the feet beneath the upper body segments, either by bringing the feet backwards under the body or by moving the body forwards over the feet. The data in Table 4 show how effective such a maneuver can be. A chair that enables the feet to be brought under it enables easier and safer rises.

CONCLUSION

These analyses suggest that the joint torque strength decreases that accompany aging and perhaps even frailty may seldom limit the ability to rise from a chair. People seem to place more importance on achieving acceptable postural stability at liftoff than they do on reducing the joint muscle strengths required to rise. In the groups we studied, the strategies chosen for rising provided the old unable with the most stability at liftoff, the old able with less, and the young with the least.

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