Perception of Postural Limits in Elderly Nursing Home and Day Care Participants

Stephen N. Robinovitch and Terrence Cronin

Biomechanics Laboratory, Department of Orthopedic Surgery, San Francisco General Hospital, and University of California, San Francisco.

This study explored whether, when compared to young community-dwelling individuals, elderly nursing home and day care participants have less accurate perceptions of their postural stability borders (postural limits). Subjects estimated their performance before executing maximum forward reaches while maintaining the feet stationary. Whereas young subjects tended to underestimate their reaching limits, elderly subjects displayed no significant difference between estimated and actual values. Furthermore, errors in estimated reach limits associated with reaching ability, with less-able reachers tending to more greatly overestimate their abilities. This suggests that elderly nursing home and day care participants, and especially those with impaired postural limits, lack the potential "safety factor" observed in young subjects of underestimating their stability borders. Therefore, the link between decreased postural limits and falls in older persons may in part be due to lack of awareness of such declines, and the resulting tendency to plan movements which create loss of balance.

Two sets of constraints determine our range of feasible movements at a given instant. The first is environmental and includes the location and structural properties of objects near or contacting our body. The second is intrinsic, and includes our muscle strength, body size, flexibility, and movement speed. A reasonable assumption is that to plan successful movements, we must accurately perceive such constraints and select motor plans which are compatible with these constraints (1-3). Although for many movements we are unaware of the computations involved, we become particularly aware of them while planning challenging movements, such as jumping a large puddle without getting our feet wet, or crossing the street with traffic approaching in the distance.

An important constraint in the execution of many tasks (e.g., reaching, bending, and walking) is postural limits, defined as the horizontal displacement of the body's center of gravity with respect to the base of support provided by the feet, beyond which stepping is required to prevent a fall (4-7). Previously, we measured the accuracy of perceived postural limits in a group of young subjects, using an experimental tool we termed the Perceived Reach Test (8). In this test, subjects estimated their performance before executing maximum-distance forward reaches from a standing position, an act which moves the center of pressure to its forward stability border. We found that subjects significantly underestimated their reaching abilities, and interpreted this as a potential safety factor acting in real life to prevent the planning of movements which create risk of loss of balance. We also found that reaching ability itself had a minimal influence on the accuracy of perceived postural limits, i.e., the best reachers were little better than the worst at predicting their abilities.

In the present study, we used the Perceived Reach Test to assess the accuracy of self-perceived postural limits in elderly nursing home and day care participants. We had little doubt that a subset of such subjects would exhibit diminished postural limits (4). However, little is known regarding elderly individuals' awareness of such declines. On the one hand, general cautiousness (9) or fear of falling (10,11) might lead them to underestimate their abilities. Conversely, simultaneous declines in motor and cognitive ability (12,13), diminished activity levels (14,15), or reluctance to admit disability might result in overestimation. In either case, the most motor-impaired individuals might be most susceptible to such influences and, therefore, exhibit the greater errors in perceived abilities. In this study, our goals were therefore: (i) to assess whether, when compared to young subjects, elderly subjects tend to more greatly overestimate or underestimate their postural limits, and (ii) to explore whether a relationship exists among elderly subjects between actual postural limits and awareness of these limits.

Materials and Methods

Subjects

Elderly subjects consisted of 23 males and 23 females, ranging in age from 71 to 94 years (mean age = 79 ± 6 SD years), body mass from 46 to 108 kg (mean mass = 67 ± 13 kg), and body height from 143 to 182 cm (mean height = 159 ± 9 cm). These individuals were either living in a nursing home (Laguna Honda Hospital, n = 11) or were participants in elderly day care centers in the San Francisco area (On Lok Senior Health Centers, n = 16; UCSF/Mt. Zion Rosenberg Center for Aging, n = 6; and Laguna Honda Adult Day Health Center, n = 13). Our intent in the recruitment process was to include all individuals from these sites who would likely be able to perform the experiment, and had no recent change in medical status.
which might cause a transient mismatch between actual and perceived abilities. Accordingly, our inclusion criteria were: (i) no occurrence within the past 3 months of major illness or injury (e.g., stroke, heart disease, fall-related injury) or change in medication use; (ii) no uncorrected visual deficit (able to correctly identify tape measure markings, as explained below); (iii) able to stand unassisted for 2 minutes; and (iv) able to understand English and correctly paraphrase instructions to the investigator. At each recruitment site, physicians and/or head nurses generated lists of all individuals who would likely meet these criteria. Members of the research team subsequently reviewed medical charts and conducted in-person interviews to assess each candidate subject's eligibility and desire to participate. All subjects provided informed consent, and the experiment was approved by the Committee on Human Research of University of California, San Francisco. No formal tests of cognitive function were administered to subjects. However, for 42 of the 46 subjects (91 percent), we noted from chart review the Folstein Mini-Mental Status Examination (MMSE) scores obtained within the 12 months prior to testing.

Young subjects included 24 males and 20 females, ranging in age from 21 to 50 years (mean age \(= 34 \pm 10\) years), body mass from 45 to 125 kg (mean mass \(= 70 \pm 17\) kg), and body height 149 to 189 cm (mean height \(= 168 \pm 9\) cm). These subjects represented all individuals aged 50 or younger who participated in our earlier study (8). All were living in the community and were recruited from posting of notices at San Francisco General Hospital and University of California, San Francisco.

Methods

The experimental protocol (termed the Perceived Reach Test) required subjects first to estimate their performance and then execute maximum-distance forward reaches. To conduct the test, the subject stood barefooted in a corner of a highly-illuminated room, with their feet approximately shoulder-width apart, arms at their sides, heels and scapulae (or lumbar spine, in cases of significant kyphosis) contacting the posterior wall, and shoulder approximately 3 cm from the left-side wall. An inch-based tape measure (with numerals 1.5 cm in height) was mounted on the left-side wall, extending horizontally at the height of the subject's acromion. The subject was then asked to inspect the tape measure and, without moving from the above-described position, estimate two parameters. The first was their “arm length,” defined as the number along the tape measure where their longest finger would reach with their arm fully extended and their trunk upright (Figure 1, left panel). The second was their “bending reach,” defined as the number along the tape measure where their longest finger would reach while bending forward as far as possible without lifting their heels (Figure 1, right panel). The difference between these two parameters in an actual reaching test is similar to functional reach (6,16), a commonly used index of postural stability.
To help ensure that estimated reach distances were based on a clear understanding of the task, subjects were shown schematics of both types of reaches (Figure 1), and were required to paraphrase instructions to the investigator. All subjects displayed adequate comprehension. Immediately after a reach estimate was provided, the investigator pointed to the corresponding location on the tape measure, and asked the subject to confirm their satisfaction, or revise the estimate, if desired. To reduce the likelihood of subjects providing reach estimates based on prediction of their arm length in inches, rather than visualization of their perceived reaching limits, we located (without informing subjects) the 5-inch mark rather than the zero mark of the tape measure at the heels. Five inches (12.7 cm) was therefore subtracted from vocalized estimates to obtain estimated arm length and estimated bending reach.

After obtaining estimated reach distances, measures were acquired of actual arm length and actual bending reach. For these trials, the tape measure was removed and replaced with a 3-mm diameter black string. This reduced subjects’ ability to identify estimated reach distances and thus to adjust their effort to duplicate these during the actual reach trials. To measure actual arm length, the subject was instructed to extend the left hand forward as far as possible, maintaining it adjacent to, but not touching, the string. The investigator ensured that while doing so, the subject maintained the heels and scapulae (or lumbar spine, for kyphotic subjects) contacting the posterior wall, and placed a light pencil mark at the location on the wall where the distal edge of the longest finger reached. Three repeated measures were acquired, and the average horizontal distance from the posterior wall to the pencil marks was taken to equal actual arm length. To measure actual bending reach, subjects were moved forward from the posterior wall (to avoid restricting posterior movement of the pelvis) to a location where two floor-mounted angle irons served as foot positioning aids. They were then instructed to reach forward, extending the left hand as far along the string as possible while maintaining the heels on the floor. Aside from the requirement of maintaining the hand level with the string and the heels on the ground, no restriction was placed on the reaching technique utilized by subjects. Once the subject attained the maximum reach distance they could hold for approximately 1 second, the investigator again placed a light pencil mark on the wall where the distal edge of the longest finger reached. In practice, this was not hard to determine, as subjects tended to move slowly to the limits of their reaching ability, and could maintain the maximum reach position for several seconds. Three repeated measures were again acquired, and the average horizontal distance from the heels to the pencil marks was taken to equal actual bending reach.

We previously described (8) high test-retest reliability for actual arm length and actual bending reach in young subjects (intraclass correlation coefficients > .9). Furthermore, previous studies have reported good stability to functional reach in elderly subjects (6). However, the ability of the Perceived Reach Test to quantify baseline perceptions of postural stability depends also on the stability of estimated reach distances. We assessed this through a separate series of experiments, using a slightly modified protocol. The results of these sessions, which indicated good within-session and between-session repeatability to the estimates, are described in Appendix A.

Data Analysis

The error in estimated reach distance was defined as the difference (in cm) between actual and estimated reaches, with positive values of error representing underestimates, and negative values representing overestimates. Estimated reach excursion was defined as the difference (in cm) between estimated bending reach and estimated arm length. Similarly, actual reach excursion was defined as the difference between actual bending reach and actual arm length.

Independent-sample t tests were used to assess whether mean errors in estimated reach distances differed between elderly and young subjects. Furthermore, single-sample t tests were used to assess whether, in both elderly and young groups, mean errors in estimated reach distances differed from zero. Finally, linear regression was used to assess whether, in both elderly and young groups, errors in estimated bending reach associated with actual reach excursion, errors in estimated arm length, MMSE score, body height, body mass, age, and gender. To account for the increased risk of a Type I error due to multiple statistical tests, a Bonferroni correction was applied, and significance assumed for \( p < .005 \). All statistical tests were conducted with statistical analysis software (SPSS Inc., Chicago, IL).

Results

Accuracy of Reach Estimates

Independent-sample t tests revealed that mean errors in estimated bending reach, arm length, and reach excursion differed significantly between elderly and young subjects (Table 1, Figure 2). In particular, when compared to elderly subjects, young subjects more greatly underestimated their bending reach (difference between mean errors in young

<table>
<thead>
<tr>
<th>Reach parameter</th>
<th>Elderly ((n = 46))</th>
<th>Young ((n = 44))</th>
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<tbody>
<tr>
<td>Bending reach (cm)</td>
<td>Estimated 97.8 ± 11.7 117.5 ± 13.3</td>
<td>Actual 95.3 ± 8.9 123.2 ± 9.4</td>
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<tr>
<td></td>
<td>Error in estimated −2.5 ± 12.3 5.6 ± 14.0*</td>
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<tr>
<td>Arm length (cm)</td>
<td>Estimated 84.1 ± 9.2 88.0 ± 7.1</td>
<td>Actual 80.9 ± 6.8 79.8 ± 6.6</td>
</tr>
<tr>
<td></td>
<td>Error in estimated −3.2 ± 8.3 −8.1 ± 7.1†</td>
<td></td>
</tr>
<tr>
<td>Reach excursion (cm)</td>
<td>Estimated 13.7 ± 8.2 29.6 ± 11.5</td>
<td>Actual 14.4 ± 8.0 43.3 ± 7.0</td>
</tr>
<tr>
<td></td>
<td>Error in estimated 0.7 ± 10.1 13.8 ± 11.7**</td>
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</table>

Cells show mean ± SD. \( t \) tests were conducted only on errors in estimated reach distances, defined as the difference (in cm) between actual and estimated reach distances. 

* \( p < .005 \); ** \( p < .001 \) compared with elderly. 
† \( p < .005 \) compared with zero.
and elderly = 8.2 cm, 95% CI = 2.6 to 13.7 cm, t = 2.9, df = 88, p = .004), overestimated their arm length (difference between mean errors = -4.9 cm, 95% CI = -8.1 to -1.7 cm, t = 3.0, p = .003), and underestimated their reach excursion (difference between mean errors = 13.1 cm, 95% CI = 8.5 to 17.6 cm, t = 5.69, p < .001).

Single-sample t tests found that mean errors in estimated reach excursion and estimated arm length differed significantly from zero in young, but not elderly subjects (Table 1). Among elderly subjects, the mean error in estimated bending reach was -2.5 cm (95% CI = -6.2 to 1.1 cm, t = -1.4, df = 45, p = .174), the mean error in estimated arm length was -3.2 cm (95% CI = -5.6 to -0.7 cm, t = -2.6, p = .011), and the mean error in estimated reach excursion was 0.7 cm (95% CI = -2.3 to 3.7, t = 0.5, p = .64). Among young subjects, the mean error in estimated bending reach was 5.6 cm (95% CI = 1.4 to 9.1 cm, t = 2.7, df = 43, p = .011), the mean error in estimated arm length was -8.1 cm (95% CI = -10.3 to -6.0 cm, t = -7.6, p < .001), and the mean error in estimated reach excursion was 13.8 cm (95% CI = 10.2 to 17.3, t = 7.8, p < .001).

Factors Associated With the Accuracy of Reach Estimates

Among elderly subjects, errors in estimated bending reach associated with actual reach excursions (Table 2, Figure 3), with less-able reachers tending to more greatly underestimate their abilities (p < .0001). This trend did not reach statistical significance in young subjects (p = .03). In both elderly and young subjects, errors in estimated bending reach associated with errors in estimated arm length (p ≤ .0002). This suggests that subjects may have estimated their bending reach by summing their estimated arm length and estimated reach excursion, a notion further supported by the lack of correlation in both young and elderly subjects between the magnitude (and accuracy) of estimated arm length and estimated reach excursion (p > .2). Among elderly subjects, MMSE did not significantly associate with errors in estimated bending reach (p = .04), and in both groups, age, gender, height, and weight did not associate with errors in estimated bending reach (p > .1). Furthermore, normalization of actual and estimated reach distances by body height had a minimal effect on the significance of reported correlations.

DISCUSSION

We found that, when compared to elderly nursing home and day care participants, young community-dwelling subjects tended to more greatly underestimate their bending reach. However, the functional significance of this result clearly depends on one’s definition of a desired “baseline” accuracy to perceived abilities. Assuming that errors in estimated bending reach represent awareness of postural limits, we have proposed that young subjects’ tendency to underestimate this parameter represents a safety factor, which helps to prevent the planning of movements that would lead to
Table 2. Results of Multiple Linear Regression on Errors in Estimated Bending Reach in Elderly and Young Subjects

| Predictor variable                  | Elderly (n = 46) | | Young (n = 44) | |
|------------------------------------|------------------|------------------|------------------|
|                                    | B    | SE(B) | Part R | p value    | B    | SE(B) | Part R | p value    |
| Actual reach excursion             | 0.84 | 0.17  | .51    | <.0001     | 0.63 | 0.28  | .28    | .03        |
| Error in estimated arm length      | 0.95 | 0.19  | .49    | <.0001     | 1.09 | 0.26  | .53    | .0002      |
| MMSE                               | -0.54| 0.26  | .20    | .04        |      |      |       |            |
| Age                                | -0.17| 0.24  | .07    | .48        | 0.06 | 0.186 | .04    | .74        |
| Weight                             | -0.07| 0.12  | .06    | .57        | -0.16| 0.14  | .12    | .26        |
| Gender                             | -1.50| 3.98  | .04    | .71        | 1.57 | 4.49  | .04    | .73        |
| Height                             | 0.03 | 0.26  | .01    | .91        | -0.04| 0.32  | .02    | .89        |
| Constant                           | 16.03| 48.09 | .74    | 2.82       | 45.74| 45.74 | .95    |            |

Dashes (—) denote nonapplicable parameter. B, partial regression coefficient; SE(B), standard error of B; Part R, part correlation coefficient; p value, two-tailed level of significance for t test of the hypothesis that B = 0; MMSE, Mini-Mental Status Examination score.

Figure 3. Relationship between errors in estimated bending reach and actual reach excursion. Multiple regression indicated that a relationship existed between the two parameters among elderly (filled circles) but not young subjects (unfilled circles), with less able reachers more greatly overestimating their performance. See text and Table 2 for test statistics.

postural instability (8). If so, loss of such conservatism might contribute to increased risk for falls.

We also found that elderly subjects with impaired postural limits (i.e., lower magnitudes of actual reach excursion) tended to more greatly overestimate their abilities. This suggests that the previously documented association between reduced postural limits and falls in the elderly (16–18) may be due not only to a decrease in the range of movements for which one can maintain stability, but also to a lack of awareness of such limitations (due, perhaps, to disuse or reluctance to admit disability) and the resulting tendency to plan movements that create loss of balance. Future studies might test this hypothesis by assessing whether awareness of postural limits predicts risk for falls, independent of physical abilities. A second hypothesis worth investigating is that an age-independent “threshold” exists for motor impairment, beyond which overestimation of abilities is likely. Although the present data suggest this possibility, they do not address whether elderly and young individuals with impaired postural limits would be equally likely to overestimate their abilities.

Although young subjects were more conservative than elderly subjects in estimating their bending reach and reach excursion, they were less conservative in estimating their arm length. We cannot explain the reason for this reversal. However, we do not view these results as contradictory. Arm reach is essentially an anthropometric parameter, whereas bending reach and reach excursion depend at least as much on physical ability (i.e., strength and flexibility) as they do on anthropometrics. We see little reason why age-related differences in self-awareness should be similar between these two regimes.

The only previous study we are aware of exploring the
importance of body awareness to age-related changes in subjects either resided in nursing homes or participated in day and memory components of cognition, the latter two of inadequacy of the MMSE to separate verbal, visual-spatial, in all of which may influence awareness of motor abilities. Finally, we found that cognitive status, as measured by MMSE score, (just) failed to associate with errors in estimated postural limits. However, this may be due to the amount of reach estimates. We consider the accuracy of the arm length estimate to serve also as a valuable control, reflecting the intactness of cognitive and sensory systems required to successfully comprehend and perform the reach estimates. However, a protocol more easily integrated into standard methods for quantifying functional reach (6) would omit arm length estimates, and have subjects estimate only their reach bending while maintaining their arm extended. Furthermore, we did not allow subjects to raise their heels during the bending reach maneuver, and some might consider this an unnatural restriction on reaching ability. Although our experience suggests that lifting the heels provides a minimal increase in bending reach, we agree that the instruction used in the Functional Reach Test (6) to “reach as far as possible without stepping” represents a more accurate (and perhaps more easily perceived) limit of postural stability. We also agree with a reviewer’s suggestion that estimates of bending reach would be better acquired with subjects moved away from the posterior wall, the presence of which might influence their perceived reach distance. Finally, we suggest that reach estimates be based on the pointer rather than tape-measure technique (described in Appendix A), as the former is more amenable to the acquisition of repeat estimates.

Several limitations exist in this study. Our elderly subjects either resided in nursing homes or participated in day care programs, and therefore further studies are required to assess the applicability of our results to community-dwelling elderly persons. Due to our inclusion criteria, our data may also have limited applicability to those with visual impairment, recent changes in medical status, or major frailty (e.g., inability to stand for 2 minutes). We did not include measures of self-efficacy, fear of falling, or activity level, all of which may influence awareness of motor abilities. Finally, we found that cognitive status, as measured by MMSE score, (just) failed to associate with errors in estimated postural limits. However, this may be due to the inadequacy of the MMSE to separate verbal, visual-spatial, and memory components of cognition, the latter two of which we would expect to influence perceived abilities.

Several investigators have commented on the potential importance of body awareness to age-related changes in balance, mobility, and ability to perform daily activities (20–22). Current efforts to characterize this have relied upon measures of self-efficacy (23,24), which has been shown to influence physical function, activity level, and risk for falls, independent of sensory, motor, and cognitive status (23). However, current self-efficacy measures provide no direct comparison between actual and perceived abilities, and therefore little information on whether an individual’s confidence in their physical abilities is justified. Techniques such as the Perceived Reach Test, which appears to be repeatable in both elderly and young subjects, should therefore represent useful adjuncts to self-efficacy measures. Such tools may also have applicability in alternative areas where the interactions between movement planning and sensorimotor, cognitive, and psychosocial status are of interest, such as physical rehabilitation following stroke or injury.

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Address correspondence to Stephen Robinovitch, PhD, Division of Orthopaedic Surgery, San Francisco General Hospital, Room 3A36, 1001 Potrero Avenue, San Francisco, CA 94110. E-mail: snr@itsa.ucsf.edu

REFERENCES

Appendix A

Repeatability of Reach Estimates

To assess the short-term reliability of estimated reach parameters, 13 young community-dwelling and 9 elderly nursing home subjects (none of whom participated in our main study, but met the same inclusion criteria) participated in a revised version of the Perceived Reach Test. Changes to the protocol were motivated by two concerns regarding the validity of repeated estimates: (i) that they should be minimally influenced by feedback between sessions of actual reaching ability (and corresponding attempts to correct for self-perceived errors in previous estimates), and (ii) that they should be minimally influenced by recollection of previous estimates and attempts to duplicate these.

To address the first of these concerns, measures were acquired in three separate test sessions, each occurring on different days over a 2-week period, of estimated arm length and estimated bending reach. However, measures of actual arm length and actual bending reach were acquired only after obtaining reach estimates during the last test session. Furthermore, subjects were instructed not to attempt actual reaches outside the testing sessions. To address the second concern, reach estimates were acquired with the tape measure removed (because the numeric scale would not be a factor), and replaced with a cylindrical pointer of 1 cm diameter and 10 cm length which extended perpendicular to the wall and could slide at shoulder height in a horizontal wall-mounted track. To acquire estimated reach values, the investigator moved the pointer slowly away from the subject, who was instructed to recite the word “stop” when it reached their estimated arm length or bending reach. The subject was then asked to confirm their satisfaction with the estimate, and given the opportunity to revise it. The corresponding distance from the heels to the pointer was then noted from a scale mounted to the underside of the track, away from the subject’s view. The pointer was then quickly returned to its original starting position. In each test session, three repeated estimates of arm length and bending reach were acquired. A separate series of tests with 15 young subjects revealed good correlation (Pearson r = .90) and no significant difference by paired t test between estimates of bending reach derived from the tape measure and pointer techniques (mean difference between techniques in estimated bending reach = 0.20 cm, 95% CI of difference = −0.98 to 0.58, t = −0.55, df = 14, p = .59).

The within-session repeatability of reach estimates was assessed by examining coefficients of variation (CVs) in the three repeated measures acquired during each test session. As shown in Table A1, these averaged less than three percent in both elderly and young subjects. Between-session reliability was assessed through repeated-measures ANOVA, which found no significant difference for both elderly and young subjects between average reach estimates in the three test sessions (p > .1), and through intraclass correlation coefficients (ICCs) in average reach estimates from the three test sessions, which ranged between .85 and .99 (Table A1).

<table>
<thead>
<tr>
<th>Table A1. Repeatability of Reach Estimates</th>
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<tbody>
<tr>
<td>Reach estimate</td>
</tr>
<tr>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>Estimated bending reach</td>
</tr>
<tr>
<td>Estimated arm length</td>
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</tbody>
</table>

*Reflects within-subject repeatability of the measure. Three repeated measures of estimated reach were acquired in each of the three sessions. Cell entries display average coefficients of variation (CV) of the three within-session measures.
†Reflects between-session reliability of the measure. Average values of estimated reach were determined for each of the three sessions. Cell entries display intraclass correlation coefficients (ICC) in these averages.