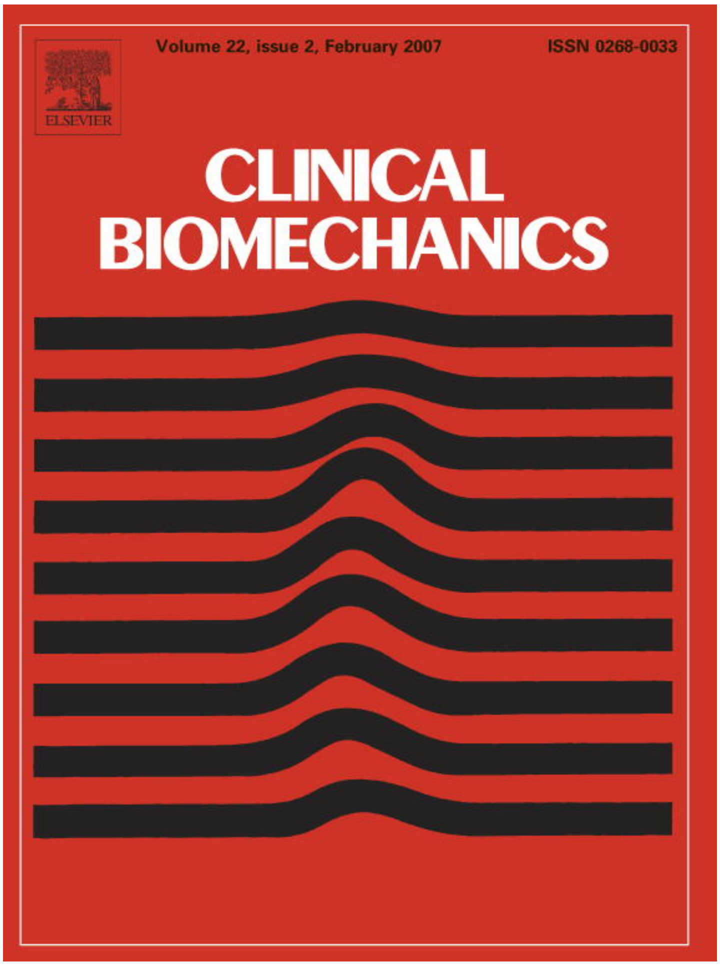
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Reaching upward is more challenging to dynamic balance than reaching forward

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Abstract

Background. Older adults have less confidence in their ability to reach upward compared to reaching forward. The forward reach test may, therefore, not be ideally suited for detecting functional deficits that directly affect daily activities.

Methods. A new test of upward reach and forward reach (along a 50-degree track) were administered to young and older adults. Reach distance was adjusted for foot length and normalized to stature. The anterior safety margin was calculated by relating the center of pressure to the base of support. The extent to which age, sex, balance confidence, anthropometric, and center of pressure parameters contribute to forward and upward reach performance was assessed.

Findings. Reach and anterior safety margin scores were well-correlated between forward and upward reaching, but the upward reach test posed a greater challenge to dynamic balance—eliciting a smaller anterior safety margin from both older and younger subjects. Further, compared to young adults, older adults showed greater limitations in reach distance and balance parameters during upward reach compared with forward reach. An observational measure of reach strategy (whether or not the heels were raised from the platform during the test) differentiated between higher and lower reach performance for older adults. Anthropometric variables accounted for much of the variance in reach performance that would otherwise have been attributed to an age-related loss of functional capacity. Balance confidence scores also contributed to regression models predicting upward—but not forward—reach performance in older adults.

Interpretation. Though upward and forward reach performances were well related in this sample, a test of upward reach may be better suited to reveal early signs of functional decline in older adults than a test of forward reach.

Keywords: Forward reach; Upward reach; Aged; Postural balance; Dynamic balance; Center of pressure; Anterior safety margin; Balance confidence; Functional assessment

1. Introduction

Reaching tasks have been recognized as being important components of the activities of daily living (ADL) that a person living independently will encounter. Powell and Myers (Powell and Myers, 1995) found that of a total of 16 activities of daily living, older adults reported that they had the highest confidence in their abilities to reach at eye level without losing balance or becoming unsteady. Conversely, these same subjects ranked their confidence in their abilities to reach on tiptoes and stand on a chair to reach as very low—only 13th and 14th on the scale of 16. Using the Falls Efficacy Scale (Tinetti et al., 1990), Powell and Myers (Powell and Myers, 1995) also found that their subjects ranked their confidence in reaching into cabinets or closets without falling as low (7th out of 10 ADL).

Even though reaching tasks are important for daily activities and older adults lack confidence in their abilities to reach in the upward direction, little is known about the upward reaching performance of older and young adults. Further, upper body movement tasks (like reaching or

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pointing) represent useful self-induced perturbations that are more difficult for older adults than for young adults (Duncan et al., 1990; Pozzo et al., 2002). In a previous study of postural control during a standing and pointing task (Pozzo et al., 2002), between 23% and 61% of the base of support was traversed during the movement, indicating that even using the upper extremity to merely point toward a target (without moving the torso to reach toward it) poses a substantial challenge to the utilization of the base of support.

The present study was designed to assess the forward and upward reaching performance of young and older adults. In addition, this study aimed to determine whether a test of upward reach (UR) would be as challenging as a test of forward reach (FR), and to determine the extent to which anthropometric variables and balance confidence during reaching activities influence reaching ability. Functional reach is usually defined as the distance beyond the outstretched arm that a subject can reach at shoulder height using a fixed base of support, and has been proposed as a clinical measure of dynamic stability (Duncan et al., 1990). It correlates moderately well with the resultant center of pressure excursion ($r = 0.71$), providing evidence that it is a reasonable measure of dynamic balance by relating to a person's ability to approach their stability limits (Duncan et al., 1990), and it has been shown to be a marker of physical frailty (Weiner et al., 1992). However, there have been conflicting reports as to whether functional reach distinguishes between older adult fallers and non-fallers (Cho and Kamen, 1998; Duncan et al., 1992; Wallmann, 2001; O'Brien et al., 1997). These conflicting conclusions may be a result of differences in the criteria used to define "fallers", and the precise method of testing functional reach, and the lack of normalizing reach scores to the subjects' stature. Further, the movement strategy required to perform the functional reach test does not replicate a movement used during daily activities, since subjects are asked to reach forward at the height of the shoulder as far as possible without stepping forward or leaning on anything. In reality, when reaching in a forward direction, there are few imaginable instances where this would be the case during daily activities; normally, since it is usually possible (and advantageous) to step forward or lean on an object (like a table) while reaching forward. A test of upward reach may prove to be a useful functional test of dynamic balance in older adults. The rationale for such a test is that older adults have rated upward reaching to be more difficult than forward reaching and that many activities in daily life require reaching in an upward direction without being able to lean on a support or to take a forward step (e.g. reaching an object on a shelf where stepping is obstructed (like a closet) or reaching upward to a light bulb).

The purposes of this study were to assess the extent to which age, sex, balance confidence, and anthropometric variables contribute to forward and upward reach performance in young and older adults, and to determine if a test of upward reach may hold additional value for the assessment of dynamic balance in older adults compared to a test of forward reach. This study tests the hypothesis that the upward reach test will elicit smaller anterior safety margins from young and older adults than the forward reach test, and that older adults will perform more poorly on the upward reach test than the forward reach test, when compared to the performance of young adults.

2. Methodology

2.1. Procedures

Young adults, 10 males and 11 females aged 24.1 (SD 3.0) yrs, and community-dwelling older adults, 17 males and 14 females aged 82.4 (SD 2.7) yrs, participated in this study. An apparatus with a sliding hand plate was built to measure both FR and UR as the subject stood centered on a force platform (Model 9287, Kistler Instrument Corp., Winterthur, Switzerland), with a comfortable (self-selected) base of support width while secured in a protective harness attached to the ceiling. The apparatus was secured to the floor adjacent to the force platform. The hand plate was constrained to slide at the height of the acromion process for FR. For UR, the sliding hand plate was constrained to incline upward at 50° from the horizontal, with the

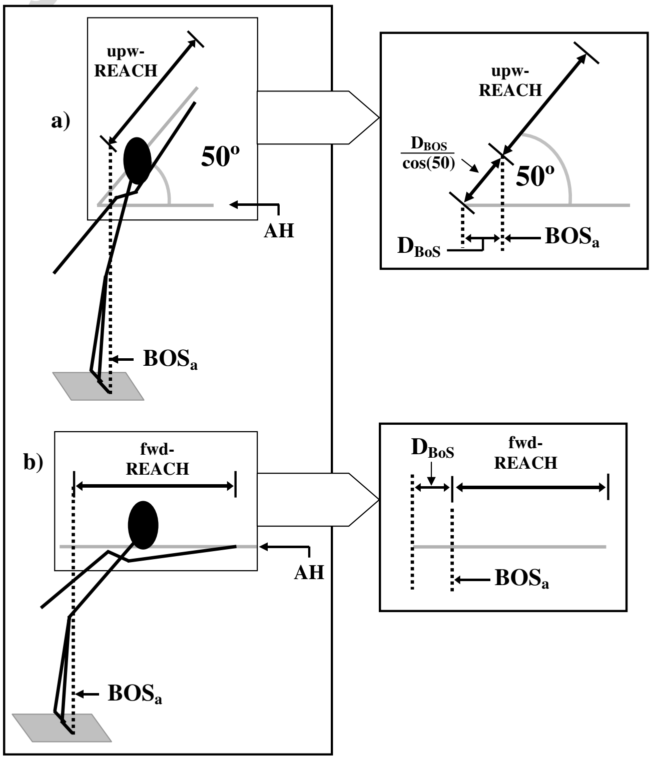

Fig. 1. Schematic of the (a) upward reach test: 'AH' is the height of the acromion process while standing, 'BOSa' is the anterior edge of the base of support, and 'upw-REACH' is the maximum distance, divided by stature, reached beyond BOSa along the 50-degree track. DBOS represents the distance between the center of the force platform and BOSa (see text); (b) forward reach test: 'fwd-REACH' is the maximum distance, divided by stature, reached forward beyond BOSa, measured along the horizontal.

fulcrum positioned at the midline of the anterior–posterior axis of the force platform (Fig. 1). For both conditions, the sliding hand plate was positioned at the midline of the medial-lateral axis of the force platform. The position of the apparatus ensured that the area of the floor in front of the subject remained clear and unobstructed to allow for stepping to occur in case of loss of balance during the reaching tests. The order of conditions was blocked by condition (FR, UR) and randomized. A mini-camera, attached to the sliding hand plate, recorded the location of a pointer aligned with a metric measuring tape. The reach scores were obtained from videotape following the data collection session, and the subjects were not informed of their performance during the testing session. A sampling rate of 200 Hz was used to collect center of pressure data from the force platform, and the subjects had as much time as necessary to complete the task. This protocol was approved by the Institutional Review Board at The Pennsylvania State University.

Subjects were instructed to push the sliding hand plate with the first knuckles (the metacarpophalangeal joints) as far as possible in the specified direction without taking a step. Subjects were shown that they could raise their heels if they desired, but that they should try not to slide their feet or take a step. Trials during which the subjects took a step were excluded from the analysis, and the number of trials in which the subject stepped was noted. Five trials in which the subject did not take a step forward were measured in each condition. No other reaching strategy was imposed on the subjects, except that the feet were placed in the same position on the force platform for each trial with the use of individualized shoe outlines and small foam positioning wedges adhered to the force platform, two behind each heel and one on the medial aspect of the ball of the foot.

2.2. Relating the center of pressure to the base of support

The subjects wore standardized shoes provided by the investigators during the data collection procedure. The soles of these shoes were scanned into a computer via a desktop scanner. The images of the shoe soles were digitized using the public domain program NIH Image (developed at the US National Institutes of Health and available on the Internet at http://rsb.info.nih.gov/nih-image/), which created an array of points representing the outlines of the soles. Following the data collection session, shoe landmarks left on the platform were digitized using a three-dimensional digitizer (Microscribe 3D, Inscribe 3.0 software, Immersion Corp., San Jose, CA, USA) to allow foot position to be determined in the force platform reference frame.

2.3. Anterior safety margin

The anterior safety margin (ASM) was defined as the distance between the anterior edge of the base of support (i.e. the distal margin of the shoes) and the maximum anterior position of the center of pressure during the trial. The ASM is similar to a safety margin measure used previously (Kozak et al., 2003) in a forward reaching study, which was based on another parameter used to quantify postural control during dynamic tasks,—the center of mass projection. In previous research, the ASM has been identified as a useful parameter for quantifying dynamic stability, representing the off-limits, or unsafe, area of the base of support (Patton et al., 1999; Koozekanani et al., 1980). In the present study, ASM was expressed as percentage of the support length (% support length), which is the anterior to posterior length of the entire base of support while performing the reaching tasks (Fig. 2). Most subjects stood with some external leg rotation with the foot abducted, thus slightly decreasing the functional anterior–posterior base of support, and therefore the support length (relative to actual shoe length). The ASM was the chosen measure of dynamic balance ability in the present study because it provided a useful assessment of the maximum usage of the anterior portions of the base of support during dynamic reaching tasks directed anteriorly.

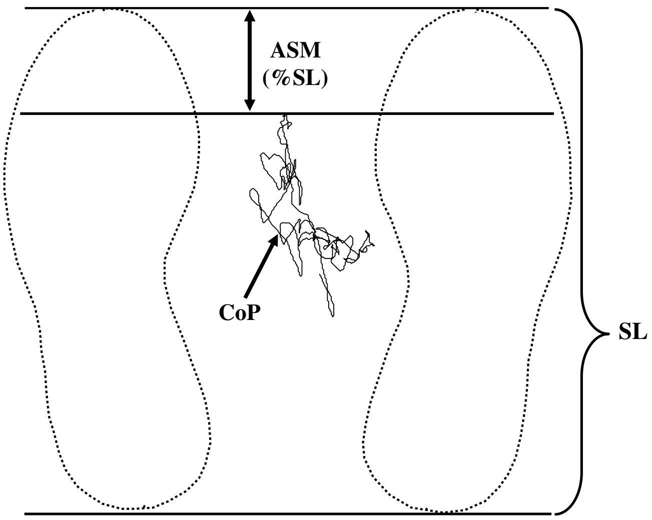

Fig. 2. The anterior safety margin (ASM) and center of pressure (CoP) from a representative trial for an older adult during forward reach with relation to the base of support for that individual. The ASM is expressed as a percentage of support length (% SL), which was the anterior–posterior length of the base of support during the reaching tests.

2.4. Reach distance

2.4.1. Upward reach

UR distance was measured along a 50-degree incline (Fig. 1). Since reaching ability is partly dependent on stature (Duncan et al., 1990), reach distances were normalized to stature (% stature). MacKenzie (Mackenzie, 1999) suggested that calculating the distance reached in front of the anterior edge of the base of support would eliminate errors in the reach distance due to inconsistencies in the starting position of the hand based on inadvertent trunk rotations and leaning. UR distance (designated upw-REACH) was therefore expressed as the stature normalized distance reached along a 50-degree incline beyond the anterior edge of the base of support, as follows:

$$\text{upw-REACH} = [(D_{\text{REACH\_UR}} - (D_{\text{BOS}}/\cos(50)))/\text{BH}] * 100 \quad (1)$$

where $D_{\text{REACH\_UR}}$ was the distance between the maximum upward reach and the center of the force platform, D_{BOS} was the distance between the center of the force platform and the anterior edge of the base of support, and BH is body height (Fig. 1).

2.4.2. Forward reach

Forward reach distance (designated fwd-REACH) was measured along the horizontal as the stature-normalized distance reached in front of the base of support. The calculation yielding fwd-REACH was similar to Eq. (1), but the distances used were along the horizontal (Fig. 1).

2.5. Reach-specific balance confidence

The Activities-Specific Balance Confidence (ABC) scale (Powell and Myers, 1995) was administered to all subjects. The average score on the ABC scale and the individual scores for the three reach-specific questions (reaching at eye level, reaching on tiptoes, and reaching while standing on a chair) were included in the regression models to address the possible influence of reach-specific balance confidence on reach performance.

2.6. Observational analysis

Video records of the data collection sessions were analyzed following testing for all reaching trials in order to qualitatively document the reaching strategies used, including trunk flexion, knee flexion, heel raise, trunk rotation and whether or not the subject took an accidental step. The presence or absence of any noticeable heel rise was visually noted during the trials and confirmed from the video recordings for each trial. The difference in the utilization of heel raise across reaching tasks and subject groups was assessed using a repeated measures analysis of variance.

2.7. Data analysis

Three-factor analyses of variance (ANOVA) with Tukey post-hoc comparisons were used to compare differences in ASM and REACH scores between age, sex, and test condition (UR vs. FR). To determine the potential for a learning effect, trial was included as a factor in all of the initial ANOVA models in order to perform a Repeated Measures ANOVA. Pearson's correlation coefficients were also used to explore the relationship between upw-REACH, fwd-REACH and ASM between the two conditions (FR and UR).

The factors responsible for the variance in reach distance were determined using regression analyses with the following parameters as factors in the models: the ASM, body mass index (BMI), arm to stature ratio, base of support to stature ratio, age and reach confidence. The most appropriate factors to use in the regression models were determined using the 'best subsets' feature of the statistical software. Using this feature, factors that are important contributors to the model even if they are not independent predictors can be identified, while minimizing the bias in the model (by monitoring Mallow's C-p). All data processing was performed using Matlab (The Mathworks, Inc., Natick, MA, USA), and the statistical analyses were performed using Minitab (v. 12, Minitab Inc., State College, PA, USA).

3. Results

A learning effect was noted for REACH and ASM scores during both UR and FR. The first and second trials always resulted in smaller REACH and larger ASM values than one or all of the remaining trials for both FR and UR (main effect for trial: $P = 0.000$–0.007 for the various measures). Since no differences were found between any parameter over trials three, four and five, and since the Coefficient of Variation (CV) decreased for most parameters when using only trials three through five, the data presented in this manuscript are the means of these three trials per subject. The CV was initially about 35% for the ASM measures for both tests and both young and older adults, and the CV for the reach distances were about 11% and 26% for young and older adults, respectively. Analyzing trials 3–5 instead of trials 1–5 decreased the CV for these measures by an average of 4.3% and 4.8% for young and older adults, respectively, excluding fwd-REACH, for which the CV increased by 2.4% and 10.9%, respectively.

3.1. Subject characteristics

There were sex and age differences in stature (Table 1). Males were taller than females, and young adults were taller than older adults ($P < 0.005$, Table 1). Males had a higher BMI than females ($P < 0.05$, Table 1), and a larger base of support length to stature ratio ($P < 0.01$), but there were no differences in arm length to stature ratio ($P > 0.05$; (Table 1).

Since the reach distance parameters were normalized by stature and the center of pressure parameters were normalized by support length, analyses of variance revealed that there were no sex differences within either the young or the older adult groups for REACH or ASM during UR or FR.

3.2. Upward reach

The average upw-REACH of older adults was only 85.6% of the average upw-REACH of young adults ($P < 0.001$, Table 2). This decrement in upward reaching ability of older adults compared to young adults was

Table 1
Subject Characteristics for young and older adults: Age, Height, body mass index (BMI), base of support length to stature ratio (BOS/st, %), arm to stature ratio (Arm/st, %)

	Age (yrs)	Height (cm)	BMI (kg m^{-2})	BOS/st (% st)	Arm/st (% st)
Young adults					
Males ($n = 10$)	24.1 (3.0)	179.2**† (7.5)	24.5^ (3.13)	16.6* (0.4)	36.5 (1.2)
Females ($n = 11$)		165.7**† (5.1)	22.0^ (1.53)	16.0* (0.4)	35.9 (1.2)
Older adults					
Males ($n = 17$)	82.4 (2.7)	172.0**† (8.4)	24.9^ (3.3)	16.6* (0.5)	37.1 (1.5)
Females ($n = 14$)		157.4**† (8.5)	22.7^ (3.14)	16.3* (0.7)	36.6 (1.8)

Sex effect, ** $P < 0.001$, * $P < 0.01$, ^ $P < 0.05$; † Age effect, $P < 0.005$.

Table 2
Stature-normalized distance reached beyond the toes in the upward and forward directions (upw-REACH and fwd-REACH, respectively, in % stature (st)) and reach distances in absolute values during UR and FR—both adjusted and unadjusted for the distance reached beyond the toes (abs-toes and abs (in cm), respectively), and anterior safety margin (ASM, in % support length (SL)) during upward reach (UR) and forward reach (FR), for young and older adults, (presented as mean (SD))

	upw-REACH (% st)	UR abs-toes (cm)	UR abs (cm)	fwd-REACH (% st)	FR abs-toes (cm)	FR abs (cm)	UR ASM (% SL)	FR ASM (%SL)
Young ($n = 21$)	35.7[a,b] (2.2)	61.5[c] (4.8)	29.3[d] (3.5)	52.0[a,b] (2.0)	89.6[c] (7.0)	46.0[d]	(4.9) 10.9[a,b] (3.9)	13.5[a,b] (3.3)
Older ($n = 31$)	30.6[b] (2.4)	50.2[c] (5.0)	17.7[d] (5.4)	46.3[b] (2.7)	76.2[c] (5.7)	33.2[d] (7.5)	23.7[b] (8.5)	25.6[b] (8.3)

[a] Young adults have smaller ASM and a larger fwd-REACH and upw-REACH than older adults ($P < 0.001$), and there were no sex differences ($P > 0.05$).
[b] For both the young and older adults, the ASM and REACH scores were significantly smaller during UR than during FR ($P < 0.001$).
[c] Absolute values of distance reached beyond toes were different between age groups and sex ($P < 0.001$).
[d] Absolute values of reach were different between age groups ($P < 0.001$).

5.1% of stature (Table 2). During UR, the average ASM for older adults was 2.1 times greater than the average ASM for young adults ($P < 0.001$, Table 2, Fig. 3), indicating that the older adults reserved a larger anterior "off-limits" zone of their base of support during UR than young adults.

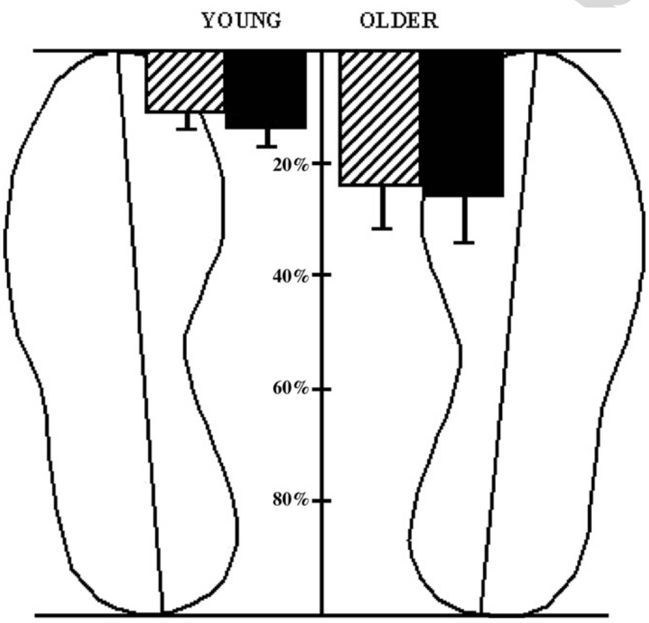

Fig. 3. Anterior safety margin (ASM) during UR (dashed bars) and FR (solid bars) for young and older adults normalized (% support length, SL; bars represent the standard deviation) and drawn to scale with respect to the same shoe outline presented in Fig. 2. The ASM was smaller during UR than during FR for both young and older adults, and was smaller for young adults than for older adults in both conditions (Table 2).

3.3. Forward reach

Fwd-REACH of older adults was 89% of the fwd-REACH of young adults ($P < 0.001$, Table 2) a mean normalized age-related decline of 5.7% of stature (Table 2). The average ASM for older adults was 1.9 times greater than the average ASM of the young adults during FR ($P < 0.001$, Table 2, Fig. 3), indicating a larger anterior "off-limits" zone of the base of support during FR for the older adults.

3.4. Comparison of upward reach and forward reach

Both upw-REACH and fwd-REACH had moderately good correlations with the respective safety margins ($r = -0.74$ and -0.71 respectively, $P < 0.000$). Upw-REACH and fwd-REACH scores were very well correlated ($r = 0.91$), as were the UR ASM and FR ASM ($r = 0.87$), indicating that the ability to reach upward and forward are well related in the samples studied. Young and older adults had a smaller ASM during UR than during FR ($P < 0.05$, Fig. 3).

3.5. Reach confidence

There was a ceiling effect noted for the reach and balance confidence scores, with the effect being nearly universal for the young adult subjects (who generally scored themselves as having 100% confidence that they could perform the activities in the scale without losing their balance). There were no sex differences in balance confidence for the reaching tasks targeted on the ABC scale ($P > 0.05$). Older adults reported higher confidence levels for reaching at eye level, compared to reaching on tiptoes or from a chair ($P < 0.001$; Table 3). The confidence scores on the latter two reach tasks were lower than the average ABC score (Table 3).

3.6. Observational analysis

The most marked difference in the observed strategy analysis between FR and UR was related to heel raise during the trials for the older subjects, especially for older males. All young adults raised their heels off of the force platform for both FR and UR. A greater number of older subjects lifted their heels during UR than during FR ($P < 0.005$), and this response did not vary between older males and females. All young adults and 58% of older adults raised their heels during FR. Of the older adults, those who raised their heels had a greater fwd-REACH (47.3 (SD 2.8) vs. 45.0 (SD 2.0) % stature; $P < 0.05$) and a smaller ASM (21.2 (SD 7.6) vs. 31.8 (SD 4.3) % support length; $P < 0.001$) than those who did not, respectively. All young subjects and 87% of older adults raised their heels during UR. As expected, the older subjects who raised their heels had a smaller ASM than those who did not (21.8 (SD 7.2) vs. 36.2 (SD 5.9) % support length; $P < 0.05$), but this did not result in a significantly larger upw-REACH (30.7 (SD 2.4) vs. 29.9 (SD 2.8) % stature; $P > 0.05$).

Other notable strategic differences between the two tests involved accidental step responses during the reaching movement. More young subjects took at least one step during the data collection session during FR and UR than older subjects. On FR, four young and five older subjects took steps at least once during the data collection session. On UR, six young and no older subjects took steps at least once during the five trials. Whether or not a subject accidentally took a step during the testing procedure may speak to the amount of risk (perhaps speed of reaching movement) the subject allows in the movement. The only other strategic difference noted between the performance on the FR and UR tests was the predominance of hip flexion during FR, but not during UR, since the objective was to reach upward. Nearly all subjects used visible trunk rotation for both reaching tests, and no subject visibly used knee flexion as a reaching strategy for either test as occurred in some previous studies (Cavanaugh et al., 1999).

Table 3
Balance confidence scores for the older adults for reaching at eye level, while on tiptoes, while on a chair, and averaged over these three reach scores (average)

Balance confidence*	Score (mean % (SD))
At eye level	93.1 (10.5)
On tiptoes	77.9 (27.0)
On a chair	64.3 (31.1)
Reach average	78.4 (19.7)
ABC	83.8 (12.4)

* The total average for the Activities-Specific Balance Confidence (ABC) scale is also shown. There were no sex differences, so the results have been combined for the older males and females.

3.7. Variability

There was markedly larger variability in the ASM of older adults than in that of the young adults for both UR and FR (UR standard deviation (SD): 3.9 and 8.3, FR SD: 3.3 and 8.0, for young and older adults, respectively). This suggests that there were considerable strategic differences within the older group; in particular, it appears that some of the older subjects were extremely cautious about utilizing the anterior regions of their base of support (shifting their weight onto their toes) by raising the heels while reaching. This difference in variability was not present in the scores for upw-REACH or fwd-REACH. For FR, those older adults who did not raise their heels from the platform while reaching had a smaller variability (SD: 4.3) than those who did use a strategy of heel raise (SD: 7.6). The trend was the same for UR (flat-footed SD: 5.9 vs. heel raisers SD: 7.2). This indicates that much of the added variability in the ASM for older adults is likely due to their within-group variable use of the heel raise strategy, since it was only measured as a binary indicator representing many levels of heel raise.

3.8. Regression analyses of reach performance

In the following regression models, some of the factors included in the model are not independent predictors of reach performance, but their inclusion in the model strengthened the model's predictive power by contributing to the model while not increasing the bias (confirmed by using the adjusted R^2, which accounts for having more factors in the model, and Mallow's C-p, which confirms that a model is unbiased if it is equal to or less than the number of parameters included in the model). The factors found to best explain the variance in fwd-REACH and upw-REACH are listed in Table 4. Alone, age accounted for 57% of the variance in fwd-REACH in a very biased model (Mallow's C-p = 17.4), but when taking the above anthropometric variables into account, age accounted for only an additional 14.1% of the variance above that accounted for by the other factors in the model, which was unbiased (C-p is equal to four, which is also the number of parameters in the model).

The factors explaining the variance in upw_REACH are also listed in Table 4. This model varies from that accounting for the variance in fwd-REACH, where the base of support length to stature ratio was not a contributor to the

Table 4
The factors present in the best models predicting the variance in reach performance are listed

Factors	Regression coefficient (β)	
	fwd-REACH (R^2adj = 68.3%[**])	upw-REACH (R^2adj = 67.3%[**])
For all subjects		
FR ASM	−0.205[**]	−0.168[**]
Age group	−0.038[**]	−0.033[**]
Arm-BH ratio	0.509[*]	0.620[*]
BMI	0.001[a]	0.002[a]
BoS-BH ratio	N/A	−1.24[*]
For older adults only		
	fwd-REACH (R^2adj = 33.2[**])	upw-REACH (R^2adj = 41.3[*])
FR ASM	−0.187[**]	−0.138[**]
Sex[b]	0.010[a]	0.010[a]
Arm-BH ratio	0.575[*]	0.790[**]
BoS-BH ratio	N/A	−1.68[*]
BMI	N/A	0.001[a]
ABC-eye	N/A	−0.001[a]
ABC-toes	N/A	0.0002[a]

Factors that are not independent predictors are also included, since they were identified as being a part of the best model using the R^2-adj and Mallow's C-p.
ABC-eye = activities-specific balance confidence while reaching at eye-level.
ABC-t = activities-specific balance confidence while reaching on tip-toes.
Arm-BH ratio = the ratio of arm length to body height.
BoS-BH ratio = the ratio of the length of the base of support to body height.
N/A = not applicable, the parameter is not present in the best predictive models.
[a] $P > 0.05$ but the factor was a part of the best model.
[b] (where 0 = male, 1 = female).
[*] $P < 0.05$.
[**] $P < 0.005$.

model, and body mass index contributed much less. Taken alone, age accounted for 53.3% of the variance in upw-REACH in a very biased model (Mallow's C-p = 20.6), but when taking into account the effects of the above anthropometric parameters, age accounted for only an additional 12.9% of the variance above that accounted for by the other predictors in the model, which was unbiased (C-p is equal to 5.1, which approximates the number of parameters in the model, signifying an unbiased model).

When including only the data for the older adults so that the balance confidence scores could be taken into account (since there was no variation in balance confidence scores of the younger adults), the models best accounting for the variance in fwd-REACH and upw-REACH are listed in Table 4. Balance confidence scores were present only in the model best accounting for performance on upw-REACH, and not fwd-REACH in the older adult group. While these parameters were not independent predictors of reach performance, their presence in the best models (highest R^2-adj) with lowest bias (Mallow's C-p) signify that they contribute to the model, even while not being independently predictive.

4. Discussion

Reaching upward has been reported by older adults as one of the most challenging tasks they face in daily life (Powell and Myers, 1995). The present cross-sectional study confirmed that finding, and showed that age-related differences in reach performance are somewhat greater during a test of upward reach compared to forward reach. Regression analyses revealed that the anterior safety margin, anthropometric measures (arm to stature ratio, base of support to stature ratio), and age predicted stature-normalized reach performance. Balance confidence during reaching activities further contributed to variations in reach performance in the upward—but not the forward—reach test.

When comparing reach performance in absolute values, the young subjects included in this study reached farther forward than the young adult group in previous research (42.7 (6.4) mm for males and 37.4 (5.0) mm for females, respectively (Duncan et al., 1990)), but it is possible that these differences are due to the inclusion of a very broad age range in the young adult group of the previous study, or to potential differences in the way the starting position of the reaching movement was defined. The older adults studied in the present paper appeared to have about the same forward reach abilities as the older adults in previous research (30.8 (4.9) mm for males and 28.5 (5.2) mm for females, respectively (Duncan et al., 1990)). While light touch with an external object (haptic support) can affect postural sway in static postural conditions (Krishnamoorthy et al., 2002) and during standing with dynamic arm movements (Slijper and Latash, 2000), it is unknown whether it affects postural control during dynamic balance tasks such as reaching. It is possible that there was some effect of haptic support on the subjects' postural control during the reaching tasks since they were constantly pushing on the sliding hand plate. However, in a previous study there was no difference in reach score between an electronic method using a sliding hand plate and the yardstick method of functional reach (Duncan et al., 1990), therefore it is unlikely that the sliding hand plate method used in the present study had any dramatic affect on reach performance for FR or UR.

Compared to the young adults, the normalized decrement in reach distance was somewhat greater in the upward reach test (11% vs. 14.4% for FR and UR respectively), indicating that this test represented a greater challenge to the older adults in this study. Further, though there were only sex differences in body mass index but no sex or age group differences in arm length to stature ratio, the variations in these measures were enough for them to be important factors predicting reach distance for both forward and upward reach. While the decrements in the *raw* (non-normalized and not adjusted for the distance reach beyond the toes) reach scores of older adults compared to young adults were more dramatic. with a 27.8% difference in FR and a 39.6% difference in UR (Table 2), the decrements in the *stature normalized* reaching ability of the older subjects were relatively modest given the six-decade span of mean ages (11 vs. 14.4% in FR and UR, respectively). Differences in body dimensions (mostly due to age-related height differences) account for much of this decrement. Therefore, in order to avoid erroneously over inflating true age-related (and sex-related) differences in functional capacity, it is important to normalize reach scores to stature (Duncan et al., 1990), and to include only the distance reached beyond the toes to account for differences in body posture at the start of the movement (Mackenzie, 1999). Even still, the coefficients of the regression models revealed that a large ratio between arm length and stature would lead to *increased* reach performance, and these ratios would both increase over time with age-related losses in height. Therefore, a normalized reach performance evaluation in an older adult who has experienced substantial height loss over the years may be elevated because of the change in the ratio between arm length and stature. The fact that the older subjects in this study had markedly larger anterior safety margins and only moderately reduced reach scores compared to the young subjects may underscore the influence that the ratio of arm length to stature has on reach performance comparisons across age groups. However, to go so far as to normalize reach distances to both arm length and stature results in a value that would not be appealing to clinicians. In light of these factors, it remains prudent to normalize reach performance as the distance reached beyond the toes divided by stature, in order to improve between-subject comparisons.

There was a marked difference between the young and older subjects regarding the use of the base of support. The older subjects maintained an ASM that was 1.9 and 2.1 times that of the younger subjects during FR and UR, respectively. While some older subjects explored distal regions of the base of support similarly to the young subjects, several others were unwilling or unable to move the center of pressure beyond 34% of support length from the anterior edge of the base of support. Even those older adults who exhibited some heel raise during the reach tests did not decrease the ASM to the level of the young adults (FR: 21.2 vs. 13.5% support length, UR: 21.8 vs. 10.9% support length, for older and young adults, respectively). Increased sway during quiet stance among older adults can also be an indicator of fall risk (Maki et al., 1994), but during tests where the maximal functional base of support is explored during the limits of stability test, it is a *decrease* in the measure that signifies a loss of function. The present study confirms that older adults do not (or cannot) utilize as large of an excursion of the center of pressure to the limits of their base of support to the extent that young adults do (Murray et al., 1975). Though not included in the present study, it is likely that the strength of various lower extremity muscle groups influenced the performance of the older adults on the two reaching tasks (Binda et al., 2003). Further, the regression analysis of reach performance for the older adults revealed that the balance confidence scores while reaching help explain some of the variance in upw-REACH, and not fwd-REACH. This, along with the lower than average balance confidence during upward reaching activities than during other ABC activities (Table 3) seem to be further indication that reaching in an upward direction is a more challenging task for older adults compared to reaching forward.

The inter-test correlations for reach distances and center of pressure measures are high enough to indicate that testing the performance on one test (i.e. FR) would be sufficient for predicting performance on the other (UR). However, the following five important contributions of the UR test are not revealed by a correlational comparison:

1. Older subjects showed greater decrements in UR than FR compared to the younger subjects, and it is probable that these decrements would be more amplified in a group of older adults who are functionally impaired, given the increased challenge of UR compared to FR as measured by the ASM and balance confidence constructs.
2. The fact that the UR test elicited a smaller ASM from both young and older adults during UR indicates that the UR test is able to parcel out more advanced reaching ability (in that it caused further use of the base of support than during FR), and therefore determine when subjects/patients are at the beginning stage of a loss in dynamic balance function. Clarification of when this advanced component of reaching function is lost with age and disability may result from studies aimed at older adults of a broad age range, and those with the onset of functional impairment.
3. Even though the older group had a smaller ASM during UR than FR, it was still larger than that of the young adult group (even in those who utilized heel raise). From this study, it is not possible to know at which age older adults begin to lose upward reaching abilities, but it is likely simultaneous with decrements in plantarflexor and toe flexor muscular strength, since the strength of this and other muscle groups are related to the ability to sustain large center of pressure excursions during the limits of stability test (Binda et al., 2003). The same study showed that the center of pressure excursion was also negatively related to a fear of falling and low balance confidence (Binda et al., 2003). Balance confidence contributed to upw-REACH performance for older adults in the present study.
4. The fact that a higher percentage of older adults raised their heels during UR than during FR confirms that upward reach is a more dynamic test of balance, causing the greater excursion of the center of pressure into the anterior regions of the base of support. The absence of heel raise during UR may prove to be a simple early flag of a loss of dynamic balance abilities in future studies.
5. A greater number of older adults accidentally took a step during FR than during UR. This may be reflective of two things: (1) the movement used during FR is novel

(likely not a replication of forward reaching movements used in daily activities), therefore increasing the risk of destabilization during the unusual forward trunk rotation, and (2) older adults are less willing to aggressively explore their limits of stability during the UR test, adopting a more controlled approach—thus making them less likely to require a recovery step during the trial.

There was substantially higher variability in the anterior safety margin of older adults compared to young adults, but there was not a concomitant increase in the variability of reach distance. The high variability in ASM for older adults can only be partially attributed to the varying degrees of heel raise, since variability was only partly reduced when separating the older adults into 'heel raisers' and 'flat-footed' subjects. It is possible that gradations in the amount of heel raised utilized, variations in plantarflexor strength, differences in foot anthropometry, and variations in reach strategy also contributed to the variability of the ASM.

Quantifying the precise nature of any potentially different strategies that might further contribute to the age-related differences in reach performance beyond the difference due to anthropometric variations is beyond the scope of the present study, since motion analysis was not a component of the methodology. However, it was observed that older adults were more likely to utilize heel raise as a strategy during UR, and less likely during FR. Previous research has also indicated that a higher proportion of younger subjects utilize heel rise during a forward reaching task than older subjects (Cavanaugh et al., 1999). Unlike a previous study where subjects were asked to reach as far forward as possible regardless of reaching height (Cavanaugh et al., 1999), knee flexion was not visibly utilized by any subject during the data collection procedure for either FR or UR since it naturally offered no advantage to reaching forward at a height that was constrained at the height of the shoulder, or in a 50-degree upward incline. It is possible that reaching velocity, which was not measured in the present study, was also part of the strategy used to maximize reach, since previous research showed that older and young adult females reach farther at a comfortable pace than at a fast pace, and the comfortable pace for older females is slower than for young females (Kozak et al., 2003). Since the subjects in the present study were allowed to reach at a comfortable pace, it is likely that they were able to maximize their reaching capabilities regarding both reach distance and ASM.

It must be noted that advanced kyphosis would seriously alter an individual's ability to perform the upward reach test. One subject who volunteered for the study was unable to perform UR because of the extent of her kyphosis. She was simply unable to both see and reach upward at 50° from horizontal long enough to complete a trial. Another subject chose not to perform UR because she reported dizziness when tilting her head upward. For this reason, these two subjects were not included in the study. Further, differing shoe sole and heel heights could confound comparing results between subjects or patients for upward reach. In clinical settings where it is not possible to standardize footwear, it may be best to perform these tests with the subjects unshod.

UR could easily be adapted for use in a clinical setting and since subjects were less likely to take a step than during FR, such a test may be safer to use without a harness. The method proposed by Mackenzie (Mackenzie, 1999), which eliminates errors in reach distance due to starting position posture could be utilized. Patients could place their toes behind a datum line for tape measurement, hold on to a rod pulling a rolling tape measure attached to a wall at the height of the acromion process, and push the apparatus along a 50-degree track on the wall, with the fulcrum as near the subject's midline as possible. Care would need to be taken, since it would be important that the subjects do not touch the wall with the side of their hand or gain mechanical support from the tape measure apparatus, thereby influencing stability during the test. A tape measure that holds the maximum measurement would allow for the reach score to be read when the patient returns to the standing position. The reach distance (which would by definition be performed beyond the toes because of the datum line) could then be standardized to stature for a more accurate representation of upward reaching ability. An alternate strategy for implementing this test in clinical settings would be to use a yardstick secured to the wall (as in the functional reach test) and constrained to a 50-degree angle. Care would also be required to ensure that the fulcrum of the incline of the stick is at the height of the acromion process, and is centered with the midline of the subject's body. In this scenario, the rater could stand upon a stepladder to read the reach distance on the yardstick.

5. Conclusions

A test of upward reach would be a useful addition to the clinical tools available for assessment of dynamic balance in older individuals. In both young and older adults, UR was found to challenge the subject to use a greater percentage of the base of support length, and older adults exhibited reduced performance on both reaching tasks compared to young adults; the reduction being more pronounced in the test of upward reach. The older adults in the present study were among the very old (over 80 yrs), and therefore likely have experienced losses in many systems that contribute to dynamic balance control, however, their losses in reach function were rather modest when accounting for body height.

An important methodological consideration has been identified in this report. It is important that anthropometric variables are accounted for when describing age-related losses in reach performance for both the UR and FR tests, since changes in such variables with aging (due to a loss of height, or to cohort-related height differences) accounted for much of the difference in reaching ability that would otherwise be solely attributed to age-related losses in functional capacity. The best way to account for the anthropometric variables while keeping the parameters clinically relevant is to measure only the distance reached beyond the toes, and divide the reach distance by stature.

Some limitations in this study include the lack of measures of reaching kinematics, strength, and proprioception, which are likely to help explain reach performance. Future studies that determine normative values for upward reach across a greater span in age would be beneficial for the development of this test for use in the early detection of unhealthy aging with respect to dynamic postural control.

The upward reach test is a test of dynamic balance worthy of future evaluation in the identification of older adults at risk of losing functional abilities. It may prove useful in tracking functional decline during longitudinal studies and, when normative data are available, for identifying individuals in need of preventative rehabilitation. Noting the use of heel raise during the test may be an early indicator of functional losses. The strengths of this test are that it is more representative of typical and difficult reaching activities encountered during daily life than a test of forward reach, and that it parcels out advanced dynamic balance function in both young and older adults.

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