Reaching upward is more challenging to dynamic balance than reaching forward

Brandi S. Row [a,*], Peter R. Cavanagh [b]

[a] [illegible]
[b] [illegible]

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Abstract

[illegible]. 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 a ect daily activities.

[illegible]. 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.

[illegible]. 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) di erentiated 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.

pointing) represent useful self-induced perturbations that are more di cult 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 (= 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 di erences 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 di cult 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. [illegible]

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

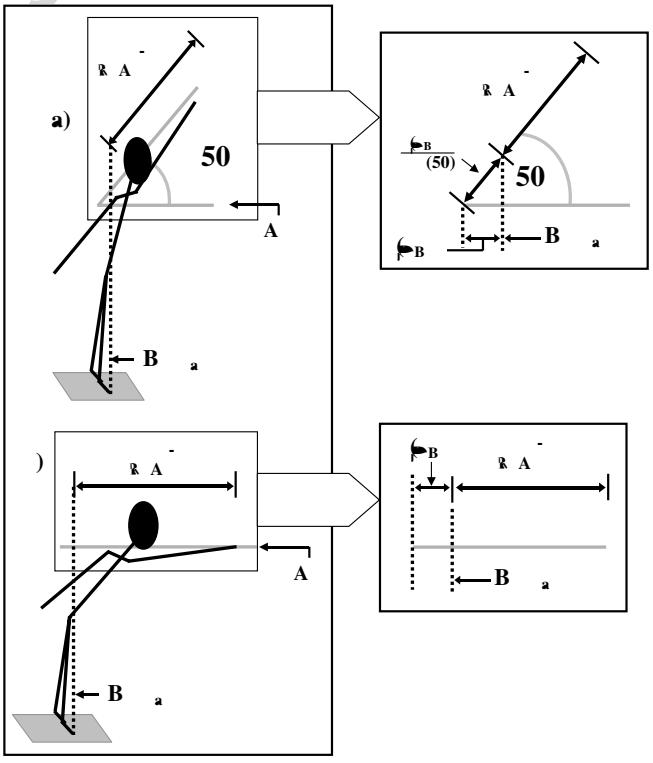

Fig. 1. Schematic of the (a) upward reach test: 'AH' is the height of the acromion process while standing, 'BOSa' is the anterior edge of the base of support, and 'upw-REACH' is the maximum distance, divided by stature, reached beyond BOSa along the 50-degree track. DBOS represents the distance between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

reached along a 50-degree incline beyond the anterior edge of the base of support, as follows:

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

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)
Males (= 10)	24.1 (3.0)	179.2**† (7.5)	24.5^ (3.13)	16.6* (0.4)	36.5 (1.2)
Females (= 11)		165.7**† (5.1)	22.0^ (1.53)	16.0* (0.4)	35.9 (1.2)
Males (= 17)	82.4 (2.7)	172.0**† (8.4)	24.9^ (3.3)	16.6* (0.5)	37.1 (1.5)
Females (= 14)		157.4**† (8.5)	22.7^ (3.14)	16.3* (0.7)	36.6 (1.8)

Sex e ect, ** < 0.001, * < 0.01, ^ < 0.05; †Age e ect, < 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 (= 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 (= 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 (< 0.001), and there were no sex di erences (> 0.05).
[b] For both the young and older adults, the ASM and REACH scores were significantly smaller during UR than during FR (< 0.001).
[c] Absolute values of distance reached beyond toes were di erent between age groups and sex (< 0.001).
[d] Absolute values of reach were di erent between age groups (< 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 (< 0.001, Table 2, Fig. 3), indicating that the older adults reserved a larger anterior ''o -limits'' zone of their base of support during UR than young adults.

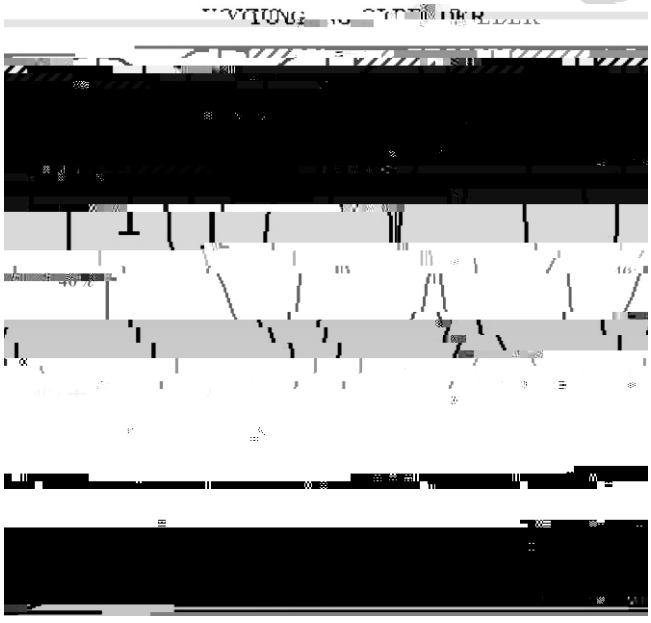

Fig. 3. Anterior safety margin (ASM) during UR (dashed bars) and FR (solid bars) for young and older adults normalized (% support length, SL; bars represent the standard deviation) and drawn to scale with respect to the same shoe outline presented in Fig. 2. The ASM was smaller during UR than during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

3.3.

Fwd-REACH of older adults was 89% of the fwd-REACH of young adults (< 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 (< 0.001, Table 2, Fig. 3), indicating a larger anterior ''o -limits'' zone of the base of support during FR for the older adults.

3.4.

Both upw-REACH and fwd-REACH had moderately good correlations with the respective safety margins (= −0.74 and −0.71 respectively, < 0.000). Upw-REACH and fwd-REACH scores were very well correlated (= 0.91), as were the UR ASM and FR ASM (= 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 (< 0.05, Fig. 3).

3.5.

There was a ceiling e ect noted for the reach and balance confidence scores, with the e ect 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

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 e ects 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 ^{2}-adj) with lowest bias (Mallow's C-p) signify

in the [illegible] 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 [illegible] 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