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Neuromuscular versus behavioural influences on reaching performance in young and elderly women

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Abstract

Falls are a major cause of injury in the elderly, and risk for falls depends on frequency of imbalance episodes. Improved techniques are required for determining how risk for imbalance during daily activities depends on behavioural (e.g., risk taking) versus neuromuscular factors. We developed a novel technique to determine whether differences exist between young and elderly women in tendency to approach imbalance during a forward reaching task. Eighteen young women (18–35 years) and 18 elderly community-dwelling women (70–87 years) participated in trials that required them to stand and reach forward to grasp as quickly as possible a target that moved back and forth, in and out of reach. We conducted 21 trials with each subject, varying the target distance at the time of the go cue, to measure how closely subjects would approach their maximum reach distance, beyond which imbalance would occur. On average, elderly women approached 65 ± 13% (S.D.) of their maximum reach on the first trial, while young women approached 84 ± 11%. Subjects became more confident over multiple trials, with the 75th percentile in voluntary reach averaging 79 ± 8% of maximum reach in elderly, and 89 ± 4% in young. Tendency to approach maximum reach did not associate with Activities Balance Confidence (ABC) scores, or with maximum reach itself. These results indicate that, even in the absence of fear of falling, elderly women are less likely than young to approach imbalance during forward reaching. Furthermore, physical capacity and cautiousness contribute independently to reaching behaviour in these individuals.

Keywords: Balance; Falls; Reaching; Balance confidence; Postural stability; Aging

1. Introduction

Falls are a major health problem in the elderly with over 30% of individuals over age 65 falling at least once a year [1]. While growing evidence exists of the risk factors and circumstances surrounding falls, significant challenges remain in our understanding of their cause and prevention. In biomechanical terms, most falls can be defined as the loss of a stable upright posture due to movements (and lack of appropriate corrective actions) that displace the body's centre of gravity (COG) beyond the functional base of support (FBOS) between the feet and the ground. While slips and trips are common self-reported causes of falls in the elderly, similar in frequency are claims of "loss-of-balance", "leg gave way", "changed posture", or "don't know the cause" [2,3]. Moreover, epidemiological evidence suggests that most falls have no obvious link to environmental hazards [4], but instead result from failed attempts at performing daily activities, such as walking, turning, rising, and bending [5,6]. Furthermore, one community-based study involving 1571 elderly found that fallers believed their own risk-taking behaviour (e.g., carrying too many objects, climbing on furniture) was a more common cause of falling than their health or environmental factors [7].

Risk for imbalance and falls during such activities should depend on both the size of the FBOS, and on one's cautiousness in maintaining the COG within the boundaries of the FBOS during daily activities. However, while we know that declines occur with age in the size of the FBOS [8], little is known about whether there are also changes in individual's tendency to move the COG near the borders of the FBOS during daily tasks. Previously, we compared young adults and elderly adults who resided in nursing

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homes (or participated in elderly day cares) in their tendency to approach imbalance during a voluntary forward reaching task, using an experimental tool we termed the ''Reach Utilization Test'' [9]. In this test, subjects were required to reach forward from a standing position as quickly as possible to targets that cycled in and out of reach. We found that elderly individuals were less likely than young to approach their maximum attainable reach, beyond which imbalance would occur (voluntary reach averaged 65 ± 23% of maximum attainable reach in elderly, and 95 ± 5% in young). We also found that maximum attainable reach did not associate with voluntary reach.

We interpreted this to reflect greater cautiousness among nursing-home elderly in approaching imbalance, due perhaps to fear of falling [10–12]. However, we were unable to test this latter hypothesis, since we did not acquire measures of balance confidence or fear of falling. We also wondered whether our results might have been affected by the fact that we measured maximum attainable reach under static conditions (similar to Functional Reach (FR) [13]), while the voluntary reach trials were highly dynamic, in the sense that subjects were instructed to grasp the target ''as soon as they could reach it.'' We were particularly concerned that declines in attainable rates of muscle force generation (and corresponding centre of pressure (COP) velocities) may have reduced reach distance under dynamic conditions, especially for elderly subjects [14–16]. Finally, we were concerned that during these initial trials we moved the target back and forth by hand, and reaching performance may have been affected by corresponding irregularities in the target velocity profile.

In the present study, we used an improved version of the Reach Utilization Test to determine whether, during voluntary forward reaching movements, differences exist between young and community-dwelling elderly women in tendency to approach imbalance. We hypothesized (based on our previous findings) that elderly subjects would have a significantly smaller voluntary reach distance than young, due to smaller maximum attainable reach (a neuromuscular constraint), and increased cautiousness in approaching maximum attainable reach (a behavioural constraint). We also hypothesized that subjects' cautiousness in approaching their maximum attainable reach would not correlate significantly with actual magnitudes of maximum attainable reach, but that it would correlate significantly with independent measures of balance confidence.

2. Materials and methods

2.1. Subjects

Participants included 18 community-dwelling elderly women ranging in age from 70 to 87 years (mean age = 77 ± 5 years (S.D.)), and 18 community-dwelling young women ranging in age from 19 to 34 years (mean age = 22 ± 4 years (S.D.)). Elderly women were recruited through advertisements and posting of flyers in local newspapers and at senior recreational centres. Young women were recruited through posting of flyers at local universities.

Subjects were initially contacted by telephone and excluded if they reported a major neurological disease (e.g., stroke or Parkinson's Disease) or debilitating orthopedic problems (e.g., severe arthritis), had experienced major injuries within the past year (e.g., bone fracture), had regular episodes of dizziness or fainting, were unable to stand independently and walk a distance of 4.5 m without assistance, or were unable to understand simple directions in English. Subjects were excluded by on-site evaluation if they were unable to score greater than 24 points (out of 30) on the Folstein Mini-Mental Status Exam (MMSE) [17], had evidence of major deficits in proprioception (as measured by big toe position sense and monofilament to the dorsum of the foot), or major uncorrected problems in visual acuity (as indicated by a score of less than 20/15 on the Snellen test) and depth perception (as indicated by a score of more than 10 cm on the Howard–Dolman stereopsis test [18]). We include only females, since elderly women are more likely than men to experience falls and hip fractures, and characterizing the potentially complex effect of gender on performance is beyond the scope of this study. All subjects provided written informed consent, and the experiment was approved by the Research Ethics Committee of Simon Fraser University.

2.2. Experimental protocol

Each subject visited the laboratory on two occasions, typically one week apart. On the first visit, we acquired ancillary measures of sensory, functional, cognitive, and psychosocial status (Table 1). We characterized postural steadiness as the average velocity of the COP in the anterior/posterior direction during quiet stance for 15 s with eyes

Table 1
Descriptive characteristics of subjects by age category

	Young ($n = 18$)	Elderly ($n = 18$)
Age (years)	22 ± 4 (19–34)	77 ± 5 (70–87)
Height (cm)	163.7 ± 7.2 (154.0–180.0)	159.1 ± 5.1 (151.0–169.0)
Weight (kg)	59.1 ± 12.4 (43.3–86.4)	66.0 ± 10.3 (54.5–96.2)
Functional Reach (cm)	35.5 ± 5.4 (25.5–47.5)	31.4 ± 6.3 (18.0–40.3)
Get-Up-and-Go test (s)	9.6 ± 1.5 (7.1–11.8)	12.0 ± 2.3 (9.5–15.9)
Sit-to-Stand test (s)	7.3 ± 1.6 (4.3–10.9)	11.8 ± 3.3 (7.3–20.6)
Balance sway test[a] (cm/s)	4.0 ± 1.4 (1.3–7.0)	6.1 ± 2.2 (3.2–11.5)
ABC scale (16–80)	77.9 ± 2.6 (73.0–80.0)	72.7 ± 8.4 (49.0–80.0)
Mini-Mental Status (0–30)	29.6 ± 0.6 (28.0–30.0)	28.2 ± 1.4 (26.0–30.0)

Cell entries show mean ± 1 S.D., with range shown in parentheses.
[a] Average velocity of the COP in the anterior/posterior direction.

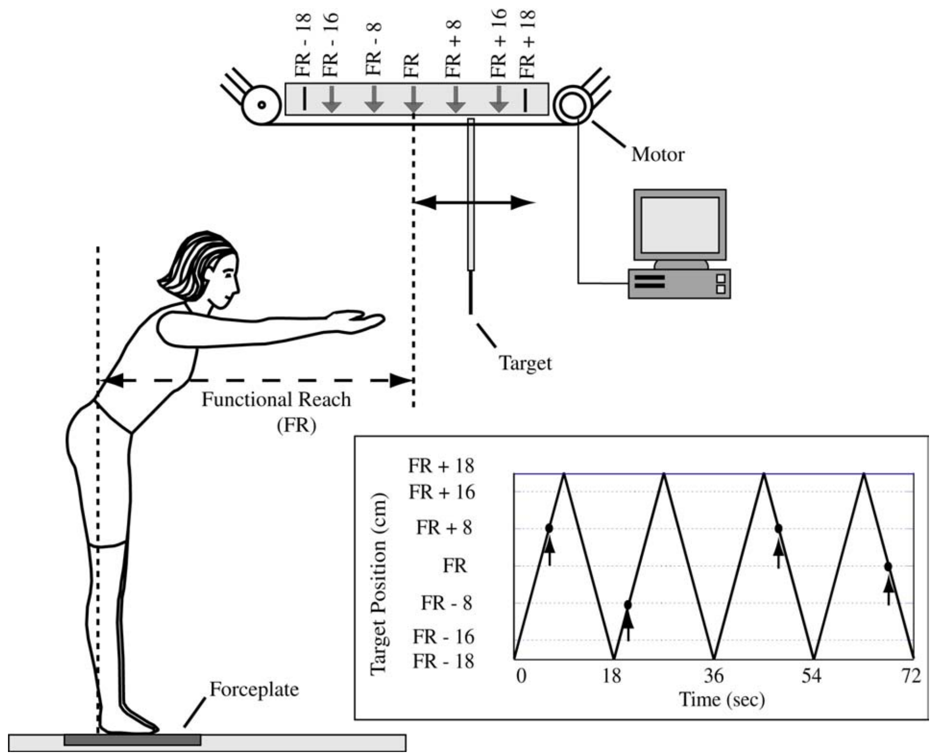

Fig. 1. Reach utilization experiment. A computer-controlled stepper motor was used to move the target towards and away from the subject with a saw tooth displacement profile, with a speed of 4 cm/s, amplitude of 18 cm, and a mean value equal to the subject's Functional Reach (FR). The subject was instructed that, upon hearing an aural go cue (a beep of 200 ms duration), she should reach and pull down the target ''as soon as she could reach it using a single continuous motion.'' The path of the target is shown in the inset, with the black circles indicating a typical sequence of target locations at the time of the go cue.

open. We measured each subject's Functional Reach, defined as the distance from the subject's heels to the tip of her longest finger, when reaching forwards as far as possible while maintaining the fingertip at the height of the shoulders when standing, and the feet shoulder-width apart and aligned in the frontal plane. In this measure (and all other reaching measures we acquired), the subject was allowed to raise her heels, but was not allowed to move her toes. This is similar to Functional Reach, a clinical measure of FBOS [13]. We also measured subject's performance on the timed Get-Up-and-Go [19] and Sit-to-Stand tests [20]. We characterized cognitive status with the Folstein Mini-Mental Status Exam [17] and balance confidence with the Activity Balance Confidence (ABC) scale [21].

On the second visit, we conducted the Reach Utilization Test [9]. This two-part test is described in detail in the following paragraphs. To summarize, it is designed to measure how far subjects are willing to reach (as a percent of maximum attainable reach), when prompted to grasp a moving target (Fig. 1). Part one of the test measures the subject's willingness or tendency to approach maximum reach, by implicitly encouraging (as opposed to explicitly instructing) subjects to reach as far as they are willing to go. To achieve this, a reaching target moves slowly back and forth, in and out of the subject's reach, and the subject is instructed that, after hearing a go cue, they should reach to grasp the target ''as soon as they can reach it.'' By varying the location of the target at the time of the go cue, the test provides a range of voluntary reach distances, the outer fringe of which represents the farthest distance the subject was willing to reach under these conditions. In part two of the test, the subjects maximum attainable reach distance is measured, for comparison with voluntary reach distances acquired in part one.

During this test, the subject stood with her feet shoulder-width apart and heels aligned in the frontal plane (Fig. 1), and was instructed to reach forward to grasp and pull down on the bottom edge of a 25 cm wide by 20 cm high cardboard reaching target (as described in further detail below). The midpoint of the cardboard edge was aligned at the height and medio-lateral position of the subject's dominant-side acromion when standing. The target was attached to a compliant spring and thereby exerted a negligible force on the hand when pulled down.

In each trial, we measured the three dimensional positions of 16 skin-surface reflective markers with a seven camera, 60 Hz motion analysis system (QTrac, Qualysis Inc., Glastonbury, CT). Markers were located at the following sites: top of the subject's head, sacrum, and left and right shoulders (acromion), elbows (lateral epicondyle), wrists (wrist joint), anterior superior iliac spines, knees (lateral condyle), ankles (lateral malleolus), and toes (5th metatarsal). Markers were also located on the floor (in line with the subject's heels), and on the reaching target. We also acquired synchronized measures of the magnitude and location of foot contact forces from a 6 degree of freedom forceplate embedded in the floor (model 6090-15, Bertec, Worthington, OH), and determined the time and position of the target at the instant it was pulled down from a contact switch. Data from the forceplate and contact were acquired at 960 Hz.

In part one of the Reach Utilization Test, we measured the subject's "voluntary reach distance." In these trials, a stepper motor was used to move the target towards and away from the subject, through a saw tooth displacement profile having an amplitude of 18 cm, a mean value of FR, a speed (between peaks) of 4 cm/s, and a period of 18 s (see inset to Fig. 1). The subject was instructed that, upon hearing the aural go cue (a beep of 200 ms duration) she should "reach and pull down the target as soon as she could reach it, using a single continuous motion." She was also instructed that, in the event the target was too far away to reach, she should "wait for it to come back, and pull down on it as soon as she could reach it." For each subject, we acquired trials at seven different combinations of target distance and direction at the time of go cue (Fig. 1). These combinations were selected so that, in at least one-half of all trials, the target was unreachable at the instant and for a substantial interval after the go cue was presented. They were: (FR − 16 cm), moving away from the subject; (FR − 8 cm), moving away from the subject; FR, moving away from the subject; FR, moving towards the subject; (FR + 8 cm), moving away from the subject; (FR + 8 cm), moving towards the subject; (FR + 16 cm), moving towards the subject. These combinations were presented in a pseudo-random manner, constrained by the requirements that (a) three trials were conducted for each combination (for a total of 21 trials), and (b) in the first trial, the target was always located beyond reach at the time of the go cue (at (FR + 8 cm), moving away from the subject). This ensured that the first trial measured naive risk-taking behaviour, before the subject had the opportunity to develop familiarity with the nature and difficulty of the task.

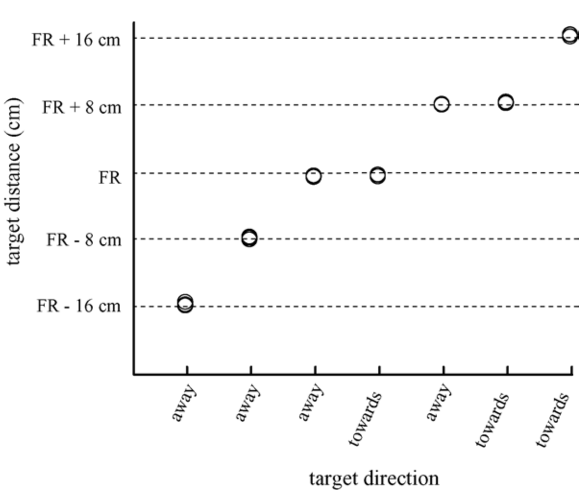

Fig. 2. Accuracy and repeatability of target presentation. The circles indicate the positions of the target at the time of the go cue for a typical subject. For each of the seven combinations of target distance and target direction, the go cue was presented within ±1 cm of the desired location.

The go cue was triggered through a manual button press by the investigator (FF) based on visual inspection of the alignment between arrows located on the target and overhead track (Fig. 1). Given the slow speed of the target, this technique allows for high accuracy, with the go target always within ±1 cm of the desired location at the time of the go cue (Fig. 2).

Subjects were allowed to lift their heels but were not allowed to move their toes (i.e., take a step). Trials where the subject missed the target or lost balance were discarded and repeated at the end of the testing session. As a safety precaution, all subjects wore a fall restraint harness that attached to an overhead support via a tether, which was slack during reaching.

In part two of the Reach Utilization Test, we measured the subject's maximum attainable reach distance under dynamic and static conditions. In these trials, the target was stationary during reaching. In dynamic trials, we instructed the subject to reach forward and pull down the target in a single continuous motion as quickly as possible, and to then return to upright standing. In static trials, we instructed the subject to reach slowly forward and hold the target for two seconds, before returning to an upright stance. In both conditions we conducted multiple trials, starting at an easy distance and moving the target 1 cm farther after each successful trial, until imbalance was detected by the need to take a step. The distance reached by the subject in the trial prior to imbalance was taken as maximum attainable reach. We shall refer to these maximum reach distances as "MAX_DYNAMIC" and "MAX_STATIC".

To minimize the effect of our observation technique on subject's reaching behaviour during the test, we always measured voluntary reach distances before maximum attainable reach. Furthermore, the information sheet given to the subject simply stated that the study's aim was "to measure movement speeds during reaching," and the investigator did not elaborate on the hypothesis to be tested.

2.3. Data analysis

We defined reach distance as the horizontal distance (in cm) from the target location at the instant of the grasp, to the location that the longest finger reached when the subject stood upright in a comfortable stance, and extended the hand forward at shoulder height, while keeping the elbow and wrist fully extended. We shall refer to reach distance in the first trial as "VOL_FIRST" and the 75th percentile over all 21 trials (representing overall behaviour) as "VOL_QUART."

We characterized subject's initial tendency to approach imbalance by the ratio (VOL_FIRST/MAX_DYNAMIC) × 100, which indicates how near VOL_FIRST was to MAX_DYNAMIC. We shall refer to this ratio as UTILIZED_FIRST. We characterized subject's overall tendency to approach imbalance by the ratio (VOL_-

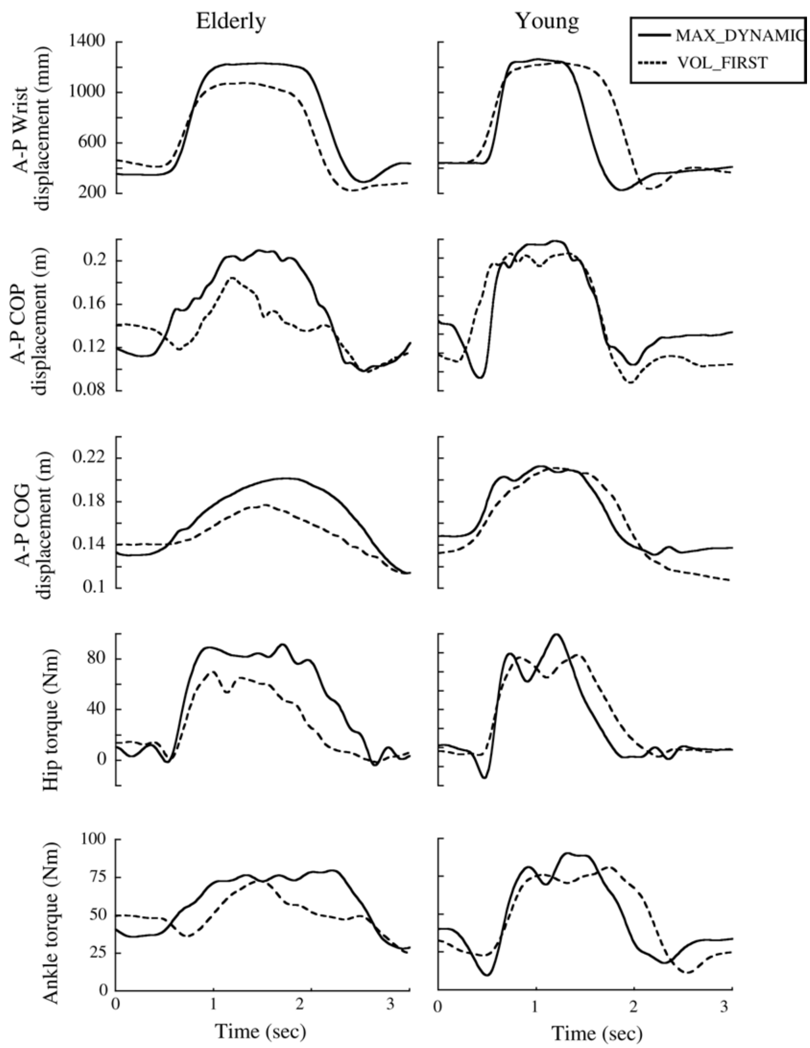

Fig. 3. Typical temporal variations in hand movement, anterior/posterior displacement of centre of pressure (COP) and whole-body centre of gravity (COG), and sagittal plane joint torques for young and elderly women during reaching trials. The solid line corresponds to the MAX_DYNAMIC trial, and the dashed line shows the VOL_FIRST trial.

QUART/MAX_DYNAMIC) × 100, which we shall refer to as UTILIZED_QUART.

We also examined for each trial the maximum anterior displacement of the centre of pressure between the foot and the ground (calculated from forceplate data) and the maximum anterior displacement of the whole-body centre of gravity, estimated from marker position data and anthropometric relations provided by Dempster [22]. We also estimated hip flexor/extensor torques and ankle dorsoflexor/plantarflexor torques using inverse dynamic. Fig. 3 shows temporal variations in these parameters for typical young and elderly women, under both VOL_FIRST and MAX_DYNAMIC conditions.

2.4. Statistics

To test our primary hypothesis, we used a *two-sided* independent-samples *t*-test to determine whether significant differences existed between elderly and young women in UTILIZED_FIRST and UTILIZED_QUART. We also examined (with independent-samples *t*-test) whether significant differences existed between elderly and young women in reach distances, COP and COG displacements, peak hip extensor torques, and peak ankle plantarflexor torques in each of the VOL_FIRST, MAX_DYNAMIC, and MAX_STATIC conditions. To test our second hypothesis, we used Pearson's correlation coefficient to determine whether UTILIZED_FIRST and UTILIZED_QUART correlated significantly with MAX_DYNAMIC, and with ancillary measures of subjects' balance confidence, cognitive status, and mobility. We regarded $p < 0.05$ to indicate significant effects. We used parametric tests for hypothesis testing after confirming through one-sample Kolmogorov–Smirnov tests that all dependant variables were normally distributed, including the ratios UTILIZED_FIRST ($p = 0.829$ for young and $p = 0.746$ for elderly), UTILIZED_QUART ($p = 0.970$ for young and $p = 0.939$ for elderly), and MAX_DYNAMIC/MAX_STATIC ($p = 0.967$

Table 2
Mean parameter values[a] separated by age

	Young	Elderly	p-value
MAX_DYNAMIC (%BH)	26.9 ± 3.4	23.9 ± 5.1	0.022
MAX_STATIC (%BH)	27.0 ± 2.9	23.9 ± 4.5	0.022
VOL_FIRST (%BH)	22.8 ± 4.9	15.8 ± 5.5	<0.001
VOL QUART (%BH)	24.1 ± 3.2	19.0 ± 5.1	<0.001
UTILIZED_FIRST (%)	84.2 ± 11.3	64.6 ± 13.6	<0.001
UTILIZED_QUART (%)	89.3 ± 3.8	78.7 ± 8.0	<0.001

%BH, percent body height.
[a] Cell entries show mean ± 1 S.D.

for young and $p = 0.560$ for elderly). All statistical tests were conducted with statistical analysis software (SPSS Inc., Chicago, IL).

3. Results

Elderly women had a smaller maximum attainable reach than young women, and were less willing in voluntary trials to approach their maximum attainable reach (Table 2; Fig. 4). Average values of MAX_DYNAMIC were 11% smaller in elderly than in young (young = 26.9 ± 3.4 cm; elderly = 23.9 ± 5.1 cm; mean difference = 3.0 cm; S.E. of the difference = 1.44 cm; d.f. = 34; $p = 0.022$). Moreover, values for the UTILIZED_FIRST were 19.6% smaller in elderly women than young (young = 84.2 ± 11.3%; elderly = 64.6 ± 13.6%; mean difference = 19.6%; S.E. of the difference = 4.16%; d.f. = 34; $p = <0.001$).

Both groups became more confident over multiple trials (Fig. 5), with UTILIZED_QUART averaging 78.7 ± 8% for elderly women and 89.3 ± 3.8% for young women (mean difference = 10.6%; S.E. of the difference = 2.1%; d.f. = 34; $p = <0.001$). However, there was correlation between UTILIZE_FIRST and UTILIZE_QUART for both elderly ($r = 0.66$; $p = 0.003$) and young women ($r = 0.68$; $p = 0.002$).

We also found that maximum attainable reach did not correlate with tendency to approach this limit during voluntary reaching trials (Fig. 4). There was a trend, but not a significant correlation, between MAX_DYNAMIC and UTILIZED_FIRST for elderly women ($r = 0.462$; $p = 0.053$), and no significant correlation between these variables in young women ($r = 0.304$; $p = 0.221$). Furthermore, there was not a significant correlation between MAX_DYNAMIC and UTILIZED_QUART for both elderly ($r = 0.332$; $p = 0.179$) and young women ($r = 0.047$; $p = 0.854$).

We found no association among elderly women between UTILIZED_FIRST and measures of balance confidence, cognitive status, and functional status. There was no *significant* correlation between UTILIZED_FIRST and the test scores on the ABC scale ($r = -0.035$; $p = 0.890$), Functional Reach ($r = 0.425$; $p = 0.089$), Get-Up-and-Go ($r = -0.026$; $p = 0.917$), Sit-to-Stand ($r = -0.197$;

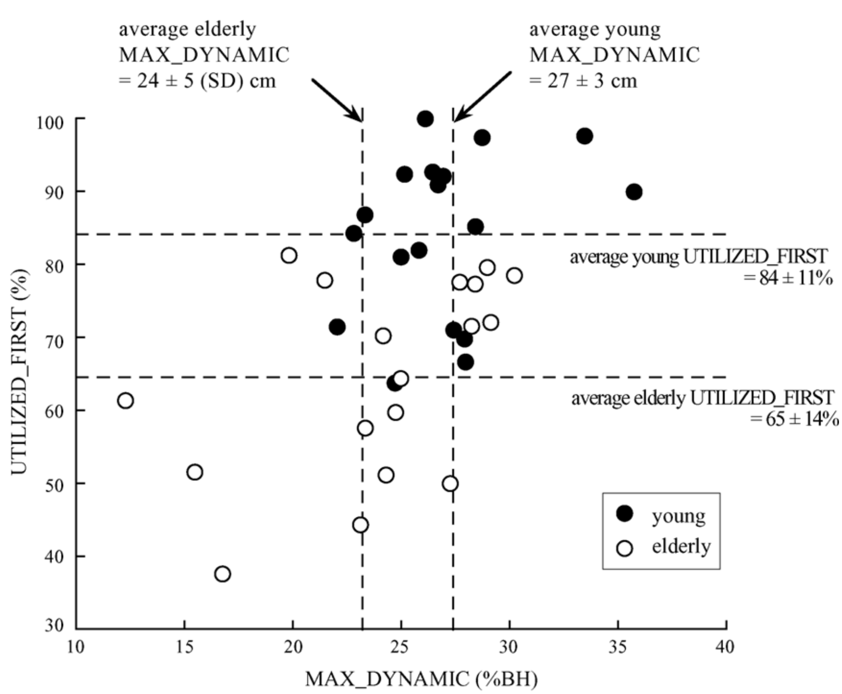

Fig. 4. Relationship between voluntary reach in the first trial (UTILIZED_FIRST) and maximum attainable reach (MAX_DYNAMIC). Average values of MAX_DYNAMIC were lower in elderly women than in young (24 ± 5%BH vs. 27 ± 3%BH; shown by the vertical dashed lines). Elderly women were also less likely than young to approach their MAX_DYNAMIC during voluntary reaching trials, as reflected by smaller average values of UTILIZED_FIRST (65 ± 14% vs. 84 ± 11%; shown by the horizontal dashed lines). MAX_DYNAMIC did not correlate with UTILIZED_FIRST for elderly ($r = 0.462$; $p = 0.053$) or young women ($r = 0.304$; $p = 0.221$). This suggests that physical capacity and cautiousness *contributed independently* to reaching behaviour in our subjects.

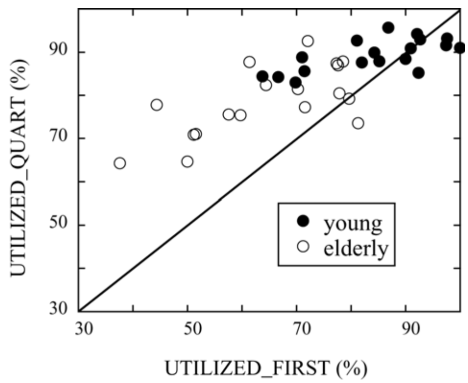

Fig. 5. Relationship between voluntary reach in the first trial (UTILIZED_-FIRST) and over all trials (UTILIZED_QUART). Both groups became more confident over multiple trials. UTILIZED_QUART averaged 79% for elderly women and 89% for young. There was significant correlation between these variables for both elderly ($r = 0.66$; $p = 0.003$) and young women ($r = 0.68$; $p = 0.002$), indicating that performance in the first voluntary reaching trial was a good indicator of overall behaviour.

$p = 0.433$), and sway during quiet stance ($r = 0.221$; $p = 0.411$). Functional Reach (when expressed as a percent body height) correlated with VOL_FIRST ($r = 0.526$; $p = 0.030$), VOL_QUART ($r = 0.620$; $p = 0.008$), MAX_-DYNAMIC ($r = 0.495$; $p = 0.043$), and MAX_STATIC ($r = 0.520$; $p = 0.032$), but not with scores in the ABC, Get-Up-and-Go, Sit-to-Stand, and postural sway tests.

For both young and elderly women, there was no difference between MAX_DYNAMIC and MAX_STATIC. Average values of MAX_DYNAMIC and MAX_STATIC were $26.9 \pm 3.4\%$ and $27.0 \pm 2.9\%$ respectively for young (mean difference = 0.1%; S.E. of the difference = 1.11%; d.f. = 17; $p = 0.711$) and $23.9 \pm 5.1\%$ and $23.9 \pm 4.5\%$ respectively for elderly (mean difference = 0.05%; S.E. of the difference = 1.30%; d.f. = 17; $p = 0.885$). This indicates that, for the range of speeds associated with our tests, reaching speed had little effect on maximum reach distance.

The difference in UTILIZED_FIRST between young and elderly women was due to differences in utilization of attainable centre of pressure excursion and ankle torque (Fig. 6). In the first voluntary reaching trial, elderly women used $88.5 \pm 7.9\%$ of their maximum COP displacement and $82.1 \pm 13.5\%$ of their maximum ankle torque observed in MAX_DYNAMIC trials. In contrast, young women used $96.2 \pm 7.5\%$ of their maximum COP displacement and $92.6 \pm 11.3\%$ of their maximum ankle torque observed in MAX_DYNAMIC trials. Interestingly, elderly and young were similar in their utilization of available hip torque (which averaged $96.9 \pm 33.5\%$ in elderly and $92.9 \pm 28.1\%$ in young).

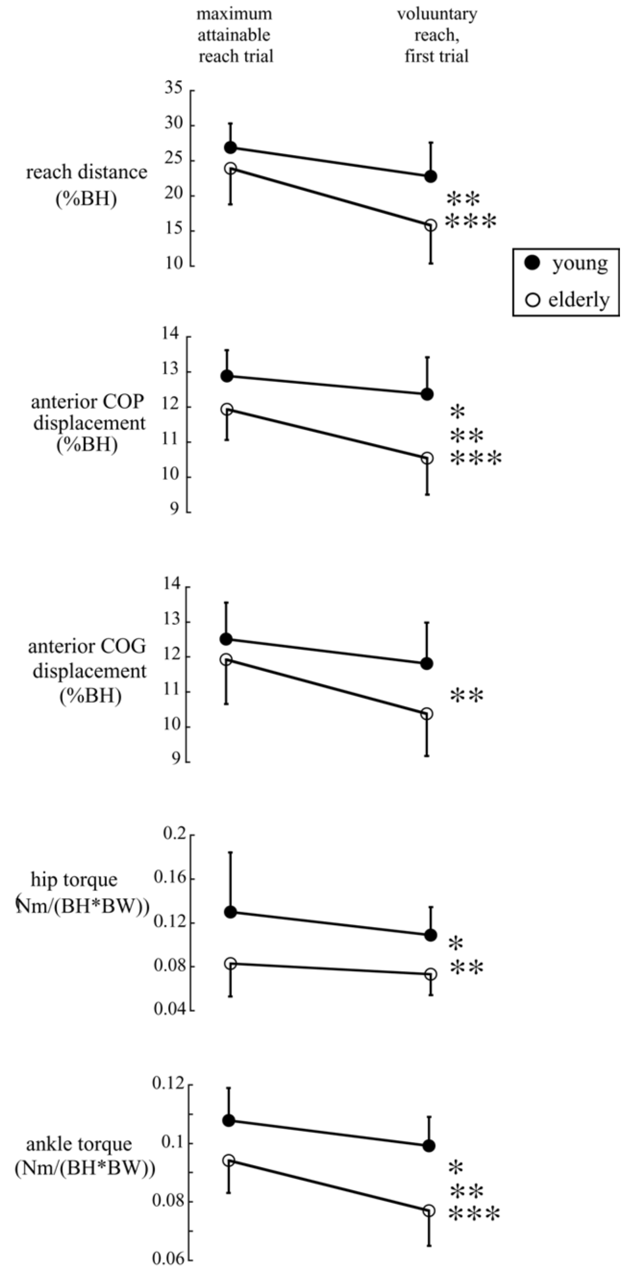

Fig. 6. Comparison between young and elderly women in reach distances, anterior COP and COG displacements, peak hip torques, and peak ankle torques in MAX_DYNAMIC and VOL_FIRST conditions. Explanation of symbols: (*) indicates that the parameter was significantly different between young and elderly in the MAX_DYNAMIC condition ($p < 0.01$); (**) indicates that the parameter was significantly different between young and elderly in the VOL_FIRST condition ($p < 0.01$); and (***) indicates that the ratio of the parameter in the VOL_FIRST to MAX_DYNAMIC conditions was significantly different between young and elderly ($p < 0.01$).

4. Discussion

We found that during the forward voluntary reaching task we examined, community-dwelling elderly women were less likely than young to approach their maximum attainable reach (and imbalance). Average values of UTILIZED_-FIRST were 23% smaller in elderly than young ($64.6 \pm 13.6\%$ versus $84.2 \pm 11.3\%$).

We also found that physical capacity and capacity utilization contributed independently to maximum voluntary reach distances. For both young and elderly women, there was no association between UTILIZED_FIRST (or UTILIZED_QUART) and MAX_DYNAMIC. This agrees with others regarding the relatively modest ability of pure motor capacities to predict task performance under daily conditions. For example, in examining the effect of exercise therapy on gait speed, Buchner et al. [10] found that strength accounted for 23% of the variation in gait speed at study onset. However, changes in gait speed occurring over the intervention period, while correlated with changes in health status and depression, were unrelated to changes in leg strength. In addition, a study examining factors that influence gait adjustment in older adults showed that sedentary older adults adopted a more cautious walking style than active ones, exhibiting shorter step lengths and slower step velocity [23]. Similarly, in the cross-sectional Women's Health and Aging Study (WHAS), Ferrucci et al. [24] found relatively modest correlations (partial R^2 values of less than 0.20) between lower extremity strength and walking speed, sit-to-stand time, and balance. These results support the notion that, while motor capacities limit our movement possibilities, motor planning and intent dictate the portion of such capacities utilized when performing daily movements.

As the trials progressed during the testing session, subjects became less cautious and more closely approached their maximum attainable reach. This trend was particularly striking among elderly women. However, we observed correlation between UTILIZED_FIRST and UTILIZED_QUART for both groups, indicating that (despite the decrease in caution over the testing session) reach utilization on the first trial was a good indicator of overall behaviour.

For both young and elderly women, we observed no difference between MAX_DYNAMIC and MAX_STATIC. This indicates that the neuromuscular demands of reaching quickly (rapid initiation and halting of COG excursion) had little effect on maximum attainable reach. This agrees with Kozak et al.'s observation that elderly women reached no farther under "comfortable" than "fast" reaching conditions [14]. Accordingly, it seems valid to express reach utilization either as a percent of MAX_DYNAMIC or MAX_STATIC [9].

Contrary to our expectations, we found that among our relatively healthy subjects, reach utilization did not associate with balance confidence (as measured by the ABC test). This suggests that tendency to approach imbalance during our reaching task may be governed by behavioural or cognitive variables (such as impulsiveness, laziness, competitiveness, or willingness to please the examiner) that are different than balance confidence. Alternatively, there may be a complex relationship between capacity utilization and balance confidence, indicating for example a reluctance to "give in" to one's fear. We also found that balance confidence did not associate with Functional Reach or Get-Up-and-Go scores, which agrees with some [11,25] but not all [12] community-based studies.

Our study had important limitations. One concerns the potential effect of behavioural factors (such as motivation and learning) on our measures of maximum attainable reach. We tried to minimize such effects by encouraging subjects in these measures to "reach a little further," until imbalance was observed. A second limitation is the potential effect on voluntary reach distances of the safety harness that all subjects wore, which may have given them security to reach further than they might in real life. A further limitation is that we measured reach utilization in a single (albeit common) reaching scenario. Finally, our subjects were all women, and therefore we cannot be certain about the applicability of our results to elderly men (who may differ in both maximum attainable reach and in tendency to approach maximum reach).

On the other hand, we took several precautions to help ensure that we measured natural reaching behaviour during the trials. Of primary importance was keeping subjects blinded to the study hypotheses, and instructing them that our goal was "to measure movement speeds during reaching." This, along with the instruction to grasp the target "as soon as they could reach it" caused subjects to believe that our primary focus was to measure movement speed and not reach distance. We also attempted to minimize the potential effects on reach utilization of both reaching speed and maximum attainable reach, by (a) using a slow target speed, (b) scaling the target path to measures of Functional Reach acquired in a previous visit, and (c) including a grasp component to provide a defined end point to the reach (although this makes it difficult to compare our voluntary reach distances to standard measures of Functional Reach). The lack of correlation between UTIL_FIRST and MAX_DYNAMIC indicates that our design was successful in isolating behavioural and neuromuscular influences on reaching performance.

In conclusion, we found that elderly women in the Reach Utilization Test were more cautious than young in approaching their maximum attainable reach, and imbalance. Tendency to approach imbalance did not associate with maximum attainable reach distance, or with balance confidence. Accordingly, we are unclear why elderly women are less likely than young to approach imbalance. While such cautiousness may protect against falls, it may also lead to reductions in mobility and hamper the performance of daily activities. The Reach Utilization Test quantifies the influence on movement patterns of true motor capacities versus behavioural variables, and appears to reflect a domain of fall risk (tendency to approach imbalance) that is independent of physical capacity and balance confidence. Future studies are required to evaluate the clinical utility of this measure for predicting risk for falls and declines in mobility in elderly populations.

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