

Elderly Nursing Home and Day Care Participants Are Less Likely Than Young Adults to Approach Imbalance During Voluntary Forward Reaching

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The goal of this study was to determine whether differences exist between young and elderly adults in cautiousness or tendency to approach imbalance during a forward reaching task. Young ($n = 26$) and elderly ($n = 25$) adults participated in trials that required them to reach forward as quickly as possible to contact a target that moved back and forth, in and out of reach. "Voluntary reach" was calculated as the 75th percentile in reach distance over 20 trials. Measures were also acquired separately of "maximum attainable reach." Voluntary reach averaged 53% smaller in elderly than young subjects. This was due to differences in maximum attainable reach, and to increased cautiousness among elderly in approaching maximum attainable reach (voluntary reach averaged $65\% \pm 23\%$ of maximum attainable reach in elderly, and $95\% \pm 5\%$ in young; $p < .001$). Thus, cautiousness in approaching imbalance reduces voluntary reach in elderly but not young subjects. Furthermore, physical capacity (as measured by maximum attainable reach) and capacity utilization (as measured by voluntary reach) are independent predictors of reaching behavior among nursing home elderly.

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Falls are a major cause of injury among the elderly, including approximately 90% of hip fractures and wrist fractures in this population (Grisso et al., 1991). Most falls in the elderly occur while performing daily activities such as walking, bending, reaching, or turning (Berg, Alessio, Mills, & Tong, 1997; Campbell, Borrie, & Spears, 1989; Hill, Schwarz, Flicker, & Carroll, 1999; Nevitt, Cummings, & Hudes, 1991; Overstall, Exton-Smith, Imms, & Johnson, 1977; Speechley & Tinetti, 1991). One's risk for imbalance during such activities depends on the size of the base of support between the feet and the ground (King, Judge, & Wolfson, 1994), and on one's ability to maintain (or reestablish) the body's center of gravity within the borders of the base of support. However, the relative importance of these two factors in the etiology of falls is difficult to determine, in part because of the lack of techniques for evaluating a given individual's tendency to approach imbalance while performing daily activities (Maki, 1997; Rosengren, McAuley, & Mihalko, 1998; Tinetti, Mendes de Leon, Doucette, & Baker, 1994). This, in turn, limits our ability to design improved techniques for preventing falls and mobility disorders in the elderly.

In the present study, we focused on the task of reaching, where for any individual there exists a specific reach distance, beyond which imbalance will occur. We were specifically interested in whether there are differences between young and elderly subjects in the tendency to approach this threshold during voluntary reaching movements. We considered that, on the one hand, general cautiousness or fear of falling might cause older adults to underestimate their abilities and utilize a smaller percentage of their maximum attainable reach (Buchner et al., 1996; Kressig et al., 2001; Maki, 1997; Tinetti et al., 1994). On the other hand, declines in cognitive ability or a reluctance to admit disability might cause older individuals to overestimate their abilities and utilize a greater percentage than young of maximum attainable reach (Robinovitch & Cronin, 1999). To address this question, we developed a new technique for quantifying subjects' tendency to approach their maximum attainable reach, via a parameter we termed the "normalized voluntary reach." We then used this technique to test the hypotheses (1) that average magnitudes of reach utilization would be different between young adults and elderly adults who resided in nursing homes or participated in elderly day care facilities; and (2) that there would be an association among elderly subjects between reaching ability and reach utilization.

MATERIALS AND METHODS

Subjects

Twenty-five elderly subjects and 26 young subjects participated in the study. Elderly subjects consisted of 11 males and 14 females, ranging in

age from 62 to 87 years (mean = 77 ± 6 years), body mass from 49 to 116 kg (mean = 67 ± 14 kg), and body height from 144 to 179 cm (mean = 160 ± 9 cm). They were either residents of nursing homes ($n = 5$) or participants in elderly day care programs ($n = 20$). Young subjects were all community dwelling, and consisted of 13 males and 13 females, ranging in age from 19 to 33 years (mean = 23 ± 4 years), body mass from 40 to 84 kg (mean = 62 ± 10 kg), and body height from 150 to 201 cm (mean = 169 ± 12 cm).

Individuals were screened by a telephone interview and a variety of ancillary measures to determine whether they meet our inclusion criteria. These were (1) able to read and understand simple directions in English; (2) able to stand independently for a period of 3 min; (3) able to walk continuously and without assistance a distance of 3 m, as measured through the Get-Up-and-Go test (Mathias et al., 1986); (4) able to score greater than 15/20 on the Snellen test of visual acuity, with habitual corrective lenses if necessary; (5) no debilitating arthritis; (6) no severe kyphosis; (7) no diagnosed peripheral neuropathy; (8) no major change within the past 3 months in medical status, or change within the past 6 weeks in the use of hypnotic or antipsychotic medications; and (9) able to score greater than 20 points (out of 30) on the Folstein Mini-Mental Status Examination (MMSE) (Cockrell & Folstein, 1988). This MMSE threshold was selected as a compromise between our competing desires to (a) screen those individuals who (due to severe dementia) would likely be unable to understand instructions, and (b) obtain a range of MMSE scores large enough to examine the relationship between cognitive status and reaching behavior. The observed range of MMSE scores in our elderly subjects was 20 to 30, with a mean value of 25.6 ± 3.5 (*SD*).

All subjects provided informed consent, and the experiment was approved by the local Institutional Review Board. During the consent process and experimental measures, subjects were informed that the goal of the study was "to measure movement speeds during reaching." At no time were they provided with additional information regarding the study hypotheses.

Experimental Protocol

The experiment measured each subject's willingness or tendency to approach (during voluntary reaching) his or her maximum attainable reach distance, beyond which imbalance would occur. To conduct the experiment, we positioned the subject standing with the hands at the sides and the toes 10 cm from the near edge of a 90-cm-high table that they faced (Figure 1). The table was covered with a sheet of white paper of surface area 61 cm by 152 cm, and a set of rails were secured over the paper. A cart having low-friction castors rested on top of the rails, which

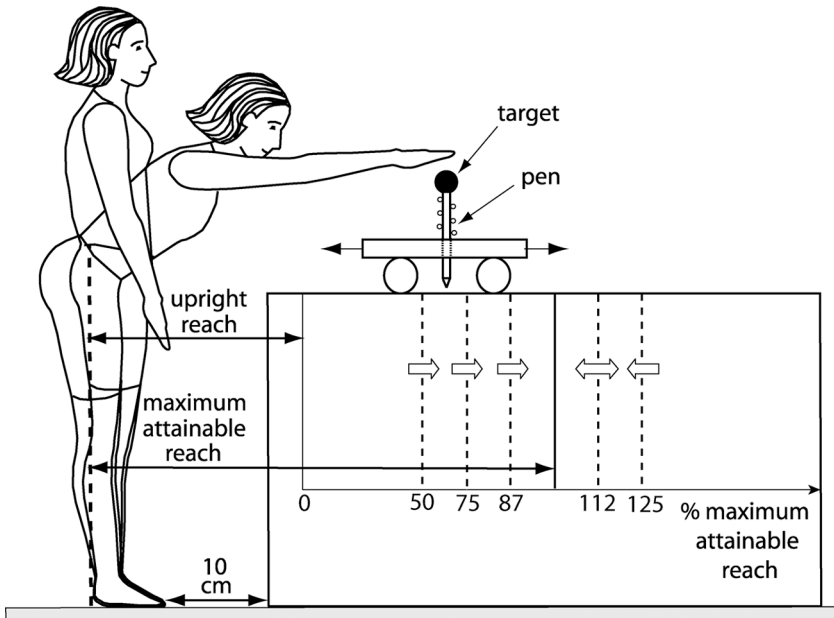


FIGURE 1 Experimental setup for measuring reach utilization. The subject stands in front of a table, upon which a cart moves back and forth, towards and away from the subject. The subject is instructed that, upon hearing an aural go cue, he or she should reach forward and strike a spherical target on the moving cart as soon as they could reach it. When the target is struck, a pen makes a mark on the underlying paper, allowing detection of reach distance. The target location at the time of the go cue is randomly varied (between 50%, 75%, 87%, 112%, and 125% of the subject's maximum attainable reach), so that in some trials it is initially beyond reach, and the subject had to wait for it to move back within reach before striking it. Through repeated trials, the test measures the maximum distance the subject is willing to reach. Upright reach is the longest distance the subject can reach while keeping the feet stationary and trunk upright. Maximum attainable reach is the longest distance the subject can reach while keeping the feet stationary and leaning forward as far as possible. The open arrows indicate the direction of cart movement at the time of the go cue for each target distance. Measures are acquired for each trial of actual reach distance (in cm), and normalized reach (defined as actual reach distance)/(maximum attainable reach) \times 100. The 75th percentile of these parameters over all trials defines "voluntary reach" and "normalized voluntary reach," respectively.

restricted motion of the cart to be along the subject's anterior/posterior axis. Six differently coloured targets (red, blue, black, yellow, green, and pink) were located on the cart, each of which corresponded to a different combination of reaching distance and direction (as explained below). The targets were arranged in a row to be equidistant to the subject, and 5 cm apart from one another. Each target was a 2-cm-diameter sphere secured to the top of a spring-loaded pen that, when the target was struck, made a mark on the paper overlying the table. This mark consisted of an indentation and ink streak the colour of the target (thus allowing for measure of reach distance).

We first conducted static reaching trials to measure the subject's "upright reach" and "maximum attainable reach." Upright reach was defined as the farthest target distant, measured from the heels, that the subject could reach while standing stationary, without bending at the waist, and without leaning forward at the ankle. This provided the origin from which all other reach distances were measured (Figure 1). Maximum attainable reach was the farthest target distance from the origin that the subject could reach without taking a step (as defined by movement of the toes) or losing balance.

We then conducted dynamic trials to determine the subject's willingness to approach the maximum attainable reach during voluntary reaching movements. In these trials, we moved the cart by hand back and forth along a path defined at one end by the origin and at the other end by 1.25 times maximum attainable reach. The movement was roughly in the shape of a triangular waveform of frequency 0.125 Hz, so that 8 s elapsed between peak-to-peak excursions. Once during each movement cycle, we provided a vocalized cue (by audibly reciting the word "RED," "BLUE," "BLACK," "YELLOW," "GREEN," or "PINK," corresponding to the color of the target to be struck) to the subject to reach forward with their dominant hand and strike one of the targets "as soon as they could hit it." We further instructed the subject that their toes must remain stationary during the reaches (lifting of the heels was allowed), and that they should return to a stationary upright position after reaching. Control of the target motion and timing of the verbal cue was approximate and controlled manually by the experimenter.

The distance from the subject to the target bank at the instant of the go cue was randomized, subject to the constraint that four trials occurred at each of six different combinations of target distance and direction of movement. These combinations, along with the slow movement speed of the target, were selected to ensure that, regardless of the subject's reaching speed, in approximately 50% of trials the target was unreachable at the instant (and for a substantial interval after) the go cue was presented. The target distances (identified by marks on the table visible to the investigator but not the subject) were 0.5, 0.75, 0.87, 1.12, and 1.25 times maximum attainable reach. For the trials involving target distances

of 0.5, 0.75, and 0.87 times maximum attainable reach, the target bank was always moving away from the subject at the instant of the go cue. For the trials involving a target distance of 1.25 times maximum attainable reach, the target was always moving toward the subject at the instant of the go cue. Finally, for a target distance of 1.12 times maximum attainable reach, trials were acquired with the target both moving toward and moving away from the subject at the instant of the go cue. This combination of close and far targets ensured that subjects remained attentive during the trials, and were provided with a sense of accomplishment through the mix of challenging and easily attainable targets (and thus did not “give up” due to the overwhelming difficulty of the task). Occasionally, the subject contacted the wrong target during the trial. When this occurred, the investigator stopped the experiment, and identified the corresponding mark on the paper to be later rejected during data analysis. The trial was then immediately repeated.

Data Analysis

At the end of each session, we carefully removed the white paper overlying the table, which had pen marks on it indicating the origin, maximum attainable reach, and reach distances for each of the 24 trials (four trials times six conditions, with each condition shown in a different color). The latter were measured as the distance from the origin to the indentation in the paper created by the pen when it first struck the paper. For all subjects, we disregarded the four trials involving target distances of 0.5 times maximum attainable reach, as these involved reach distances well below those observed in other series. For each of the five remaining conditions, we determined each subject's *average reach distance* (in cm) and *normalized reach distance* (in percent), where the normalized reach distance was given by $[(\text{actual reach distance})/(\text{maximum attainable reach distance})] \times 100$. As an indicator of overall behaviour during the trials, we also calculated the upper quartile (75th percentile) of actual reach distance over the 20 trials, which we will refer to as “*voluntary reach*,” and the upper quartile of normalized reach distance over the 20 trials, which we will refer to as the “*normalized voluntary reach*.” Therefore, throughout the manuscript we use the word “*normalized*” to indicate a percent of maximum attainable reach, and the word “*voluntary*” to refer to the 75th percentile over the 20 repeated trials in actual or normalized reach.

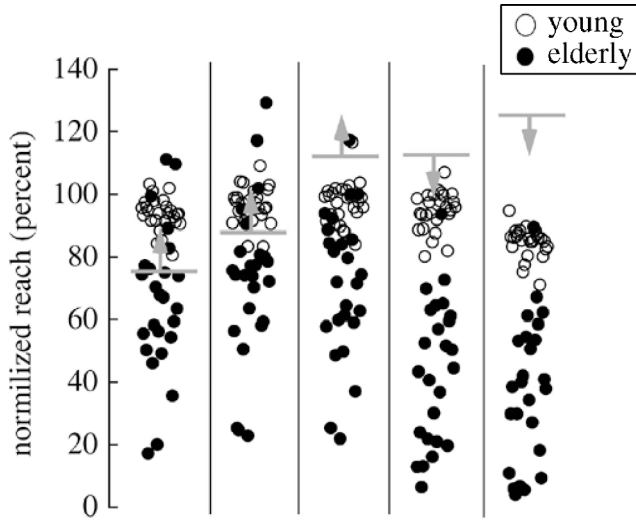
Statistics

We used a two-factor analysis of variance to test whether there was an effect of age (young versus elderly) and gender (male versus female) on mean values of normalized voluntary reach and maximum attainable reach

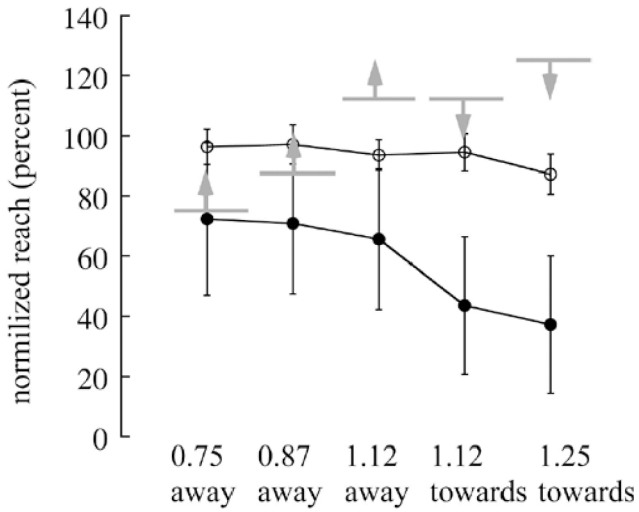
TABLE 1 Mean Parameter Values* Separated by Age and Gender

	Young			Elderly		
	Males <i>n</i> = 13	Females <i>n</i> = 13	Total <i>n</i> = 26	Males <i>n</i> = 11	Females <i>n</i> = 14	Total <i>n</i> = 25
Body height (cm)	176.41 ± 10.44	162.01 ± 8.53	169.21 ± 11.88	164.70 ± 8.35	155.62 ± 6.63	159.61 ± 8.60
Maximum attainable reach (percent body height)	32.76 ± 3.34	30.23 ± 4.84	32.49 ± 4.27	22.08 ± 5.53	21.97 ± 6.06	22.02 ± 5.71
Normalized voluntary reach (percent maximum attainable reach)	95.19 ± 2.72	94.65 ± 6.87	94.92 ± 5.12	55.55 ± 23.74	72.16 ± 21.29	64.85 ± 23.48
Voluntary reach (percent body height)	31.20 ± 3.45	28.66 ± 5.21	29.93 ± 4.52	12.31 ± 6.30	16.02 ± 7.13	14.39 ± 6.90

*Cell entries show mean ± 1 standard deviation.



(A)



(B)

(followed by post hoc *t* tests, where appropriate). We also used correlation to determine whether normalized voluntary reach associated with maximum attainable reach, and with measures of subjects' mental status (the MMSE) and mobility (as quantified by scores on the timed Get-Up-and-Go test). To account for multiple comparisons, we regarded *p* values from individuals tests to indicate significance if $p < .005$. All statistical tests were conducted with statistical analysis software (SPSS, Chicago, IL).

RESULTS

We found that, when compared to young subjects, elderly subjects had smaller attainable reach and were less likely to utilize their attainable reach. Average values of maximum attainable reach normalized to body height were 30% smaller in elderly than young subjects ($22\% \pm 6\%$ body height versus $32\% \pm 4\%$ body height; $df = 49$, $p < .001$). Furthermore, average values of normalized voluntary reach were 32% smaller in elderly than in young subjects ($65\% \pm 23\%$ versus $95\% \pm 5\%$; $df = 49$, $p < .001$; Table 1). Consequently average values of voluntary reach were 53% smaller in elderly than young subjects ($14\% \pm 7\%$ body height versus $30\% \pm 5\%$ body height; $df = 49$, $p < .001$).

In each series, mean values of normalized reach were smaller for elderly than for young subjects ($df = 49$, $p < .001$; Figure 2). The greatest difference between groups occurred in the 1.25 times maximum attainable reach condition ($44\% \pm 23\%$ versus $95\% \pm 6\%$), whereas the smallest difference occurred in the 0.87 times maximum attainable reach condition ($71\% \pm 23\%$ versus $97\% \pm 5\%$). The 0.87 and the 0.75 times maximum attainable reach condition represented conditions where the largest average values of normalized reach were observed in both young and elderly groups. There was a trend (though not statistically significant) for our elderly female subjects to have a larger normalized voluntary reach than our elderly males ($p = .082$; Table 1). However, there was no effect of gender on maximum attainable reach ($p = .356$).

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FIGURE 2 Average values of normalized reach in each experimental series. In (A), the graph shows average values of normalized reach for each subject and target condition. In (B), the graph shows average values for each group and target condition. Error bars show one standard deviation. Grey arrows, and labels at the bottom of (B), indicate the location and direction of the target at the instant of the go cue. For each series, normalized reach was smaller for elderly subjects than for young subjects, and elderly subjects exhibited greater between-subject variability in normalized reach. For both young and elderly subjects, the greatest normalized reach occurred when, at the time of the go cue, the target distance was 0.87 times maximum attainable reach.

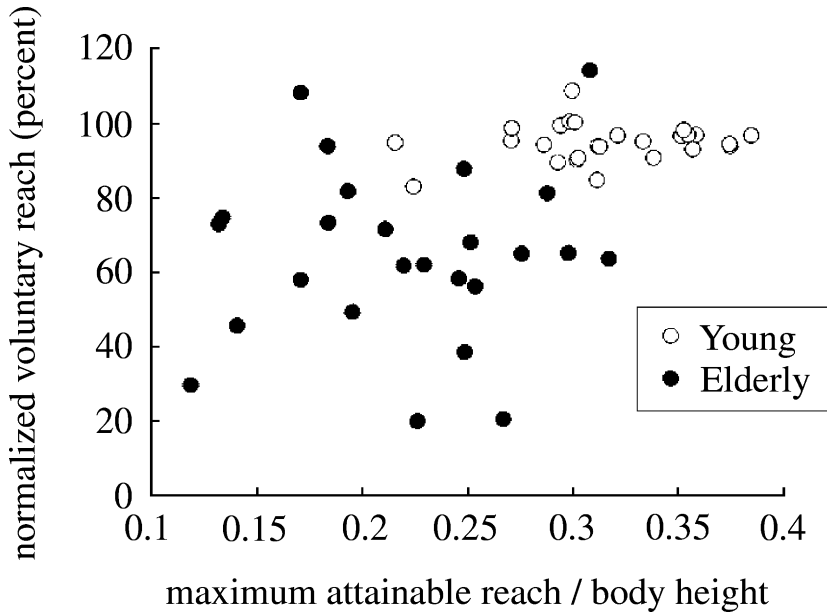


FIGURE 3 Scatter plot of maximum attainable reach versus normalized voluntary reach. There was no association between these variables for both elderly subjects ($r = .085$; $p = .682$) and young subjects ($r = .178$; $p = .385$). This leads us to hypothesize that reaching ability and utilization of reaching ability may be independent predictors of mobility and risk for falls.

Reaching ability did not associate with reach utilization (Figure 3). There was no correlation between normalized maximum attainable reach and normalized voluntary reach for both elderly ($r = .085$, $df = 24$, $p = .682$) and for young subjects ($r = .178$, $df = 25$, $p = .385$).

Among elderly subjects, Get-Up-and-Go time correlated negatively with normalized voluntary reach ($r = -0.457$, $df = 22$, $p < .002$; Figure 4a), but did not correlate with maximum attainable reach ($r = .102$, $df = 22$, $p = .643$). Also, MMSE scores among elderly did not correlate with normalized voluntary reach ($r = -.009$, $df = 24$, $p = .985$) or maximum attainable reach ($r = -.002$, $df = 24$, $p = .993$) (Figure 4b).

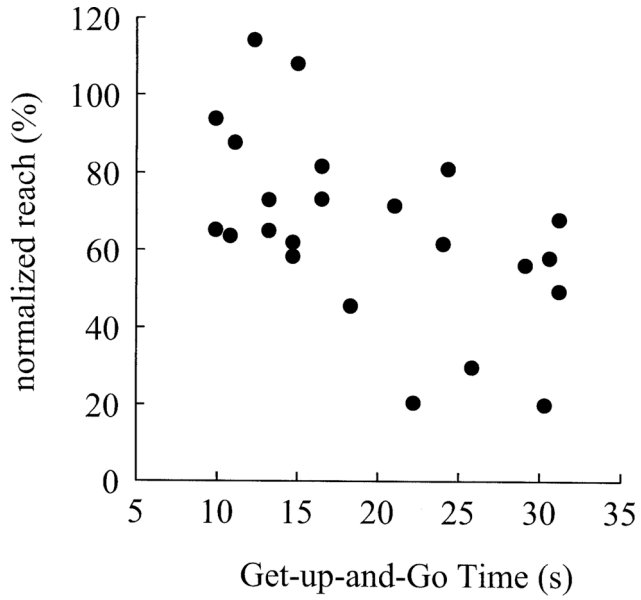
DISCUSSION

We found that elderly subjects were less likely than young to approach their maximum attainable reach during the voluntary reaching task

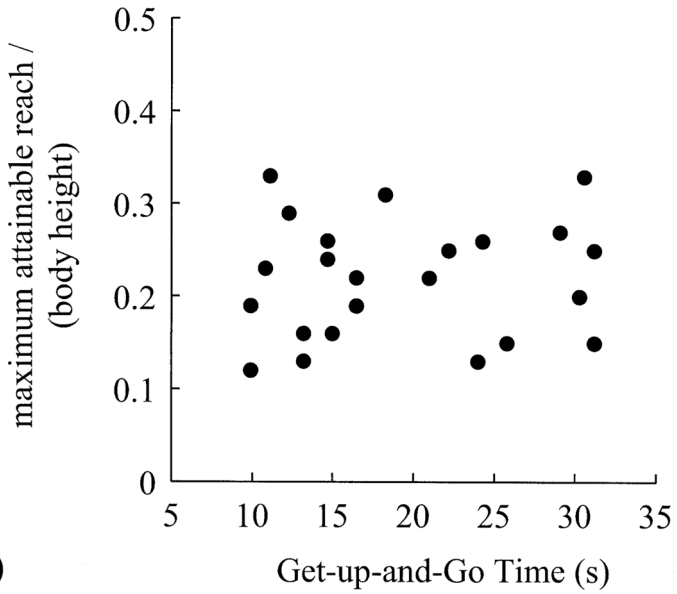
employed in our experiments. Normalized voluntary reach averaged $65\% \pm 23\%$ in elderly and $95\% \pm 5\%$ in young. This indicates that cautiousness reduces elderly subjects' voluntary reach distance by 35% on average, and young subjects' voluntary reach by only 5%. Our results also suggest that, of the mean difference in voluntary reach between young and elderly subjects of 16% body height, neuromuscular constraints account for 9.5% body height (or 59% of the total), and cautiousness accounts for 6.5% body height (or 41%).

We also found that the normalized voluntary reach did not correlate with maximum attainable reach, despite the considerable variability in each of these variables among elderly subjects. This suggests that physical capacity and capacity utilization are independent predictors of reaching behavior in the elderly. Furthermore, although gender did not associate with maximum reaching ability in our sample, there was a trend towards greater cautiousness in elderly men than women in approaching maximum attainable reach. Future studies are required to further clarify the effect of gender on tendency to approach imbalance during daily activities. Finally, we found that Get-Up-and-Go times among elderly subjects correlated negatively with normalized voluntary reach but did not associate with maximum attainable reach. This likely relates to the fact that subjects' pace in the Get-Up-and-Go test is self-selected. Therefore, as with their normalized voluntary reach, behavioral variables such as motivation and fear may strongly influence test performance.

The normalized voluntary reach provides a currently unavailable technique for quantifying the influence on movement patterns of true motor capacities versus behavioral variables. Furthermore, the "low-tech" nature of the measure should allow for easy integration in the clinical setting. However, there are several important limitations to the technique. One of these concerns the possibility that psychological factors such as motivation or fear of falling may have influenced our measured values of maximum attainable reach, as well as voluntary reach (Schieppati, Hugon, Grasso, Nardone, & Galante, 1994). To help offset this possibility, we instructed and encouraged subjects to reach as far as possible during the maximum attainable reach trials. Another potential limitation is that the reaching targets were set at the same height for all subjects, and this may have influenced subjects' reaching performance, depending on their height. Although our focus on normalized voluntary reach (i.e., voluntary reach divided by maximum attainable reach) may have helped to eliminate this confounding factor, it is possible that the "maximum attainable reach" and the "voluntary reach" were affected differently and in a nonlinear way by the table height. In addition, values of normalized voluntary reach may have been influenced not only by cautiousness in approaching a state of imbalance, but also by the accuracy of self-perceived limits of reachability, neural capacity for motor planning, musculoskeletal factors affecting the ability to move the hand



(A)



(B)

rapidly and accurately, neuromuscular factors such as reaction time and somatosensory feedback regarding limb position and contact with the target, and neural control of predictive and reactive postural adjustments. However, because of the slowness of the target speed in our trials, we believe these factors are far less important than risk-taking behavior in explaining the large differences we observed between young and elderly subjects in normalized voluntary reach. It is also possible that our results were slightly influenced by variations between trials and between sessions in the experimental conditions. For example, the cart was moved by hand, so it is likely that there were slight variations in its speed between trials and between all subjects. Furthermore, the investigator may not have always issued the aural “go” cue at precisely the same time and in the exact same way with respect to when the target passed the mark. Furthermore, variations in the investigator’s tone of voice or sense of urgency could have affected performance. Lastly, the investigator was not blinded to the study’s objectives and hypotheses, and therefore may have exhibited some unconscious bias in delivering the verbal cue. These issues could be addressed in future studies by, for example, lighting up the target instead of using an aural cue, and using a motor to move the cart. At the same time, we believe that because a single, highly trained investigator acquired all the measures, the between-subject variability in the nature of the cart movement and cueing in the current study was negligible. Certainly, we have no reason to believe that between-subject differences in experimental conditions could have accounted for the large differences we observed between young and elderly in maximum attainable reach and normalized voluntary reach.

Among the additional limitations of this study is the fact that we measured reaching behavior under a single condition, and different degrees of risk-taking may arise under alternative reaching scenarios. Also, our elderly subjects were nursing home residents or participants in adult day care programs, and therefore we cannot be certain about the applicability of our results to community-dwelling elderly (who may differ in both maximum attainable reach and in tendency to approach maximum reach). Furthermore, although we found that the normalized voluntary reach did not associate with maximum attainable reach, or with MMSE

FIGURE 4 Relationship among elderly subjects between Get-Up-and-Go time and (a) normalized reach and (b) maximum attainable reach. Get-Up-and-Go time (a standard measure of mobility) is the length of time it takes the subject at their chosen speed to: rise from sitting, walk forward 3 m, turn around and walk back, and sit down. This variable correlated significantly with normalized voluntary reach ($r = -.457, p < .002$), but not with maximum attainable reach ($r = .102, p = .643$). This indicates the substantial effect in the performance of each task of behavioral (risk-taking) tendencies.

score, further study is required to understand the associations between capacity utilization and traditional measures of behavioral and cognitive status. Moreover, we found that some subjects exhibited values of normalized voluntary reach that were greater than 100% (Figure 2a). This may reflect submaximal efforts during the trials used to measure maximum attainable reach. Conversely, it may reflect the ability in some subjects to reach farther under dynamic than static conditions, due (for example) to the influence of joint flexibility or postural sway. On a related note, the fact that our protocol prevented us from explicitly controlling reaching speed might be regarded as a limitation of our study, because reaching speed may slightly affect attainable reach distance (Pai & Patton, 1997). However, based on pilot trials with young and elderly subjects, we have found that maximum forward reach distance is nearly identical under static and dynamic conditions (as the reader can easily verify with some simple reaching exercises). Accordingly, we do not believe that interpretation of our data is complicated by between-subject differences in reaching speed.

We took several precautions to help ensure that we measured natural reaching behavior during the trials. Of primary importance was keeping subjects blinded about the true study hypotheses, and instructing them that the goal of the study was "to measure movement speeds during reaching." This, along with the instruction to contact the target as soon as they could hit 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 maximum attainable reach and reaching speed, by using a slow target speed and a target path scaled to maximum attainable reach. Our observation of no significant association between normalized voluntary reach and maximum attainable reach indicates that our study design allowed us to isolate behavioral and neuromuscular influences on reaching performance. This was best achieved in the 0.87 times maximum attainable reach condition, which involved the greatest normalized voluntary reach for both young and elderly subjects. In contrast, the greatest differences between young and elderly in reach utilization occurred in the 1.25 times maximum attainable reach condition. In this condition, the target moved within reach shortly after the go cue was presented, and therefore faster responses resulted in greater voluntary reach distances. Accordingly, movement speed seemed to influence voluntary reach distances more strongly in this condition than in the others.

Our results are in agreement with previous studies indicating that elderly individuals have smaller attainable reach distances than young (Cavanaugh et al., 1999; Duncan, Studenski, Chandler, & Prescott, 1992), and reduced functional base-of-support, or ability to maintain the centre of pressure far from the ankle during standing (Endo, Ashton-Miller, & Alexander, 2002; King et al., 1994). For example, King

and coworkers found that functional base of support (which they calculated as the difference between mean center of pressure location during sustained forward and backward leaning, divided by foot length) was 30% lower in elderly subjects than in younger subjects. This is similar to the 30% difference in normalized maximum attainable reach we observed between our young and elderly subjects. Our finding that elderly subjects tend to approach only 65% of their maximum attainable reach distance is consistent with previous studies indicating that fear of falling and cautiousness affect movement speed and task performance, independent of variables such as strength and flexibility (Buchner et al., 1996; Kressig et al., 2001; Maki, 1997; Rosengren et al., 1998). Future studies are required to examine the relationship between fear-of-falling, history of falls, and quantitative measures of risk-taking such as the reach utilization test.

In conclusion, we found that, when prompted to reach as quickly as possible towards targets that moved in and out of reach, elderly nursing home and day care participants were less likely than community-dwelling young adults to approach their maximum attainable reach. We also found that maximum attainable reach did not associate with tendency to approach this limit during the trials. This leads us to hypothesize that each may be an independent predictor of mobility and cause for falls in the elderly.

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