REACHING for an object is a common action that relies on accurate sensory and motor function to judge, plan, and execute. During standing, the body is normally balanced in a safe position with the center of mass above the central region of the base of support not moving it too close to the edge. Leaning forward stresses the demands on the balance system and the likelihood of swaying beyond the stability limit increases. Declining sensorimotor function reduces the distances that older people can lean forward (1) or be pulled forward without stepping (2). A decline in reaching performance has been identified as a predictor of falls in older people (3).

Inaccurate sensory information about the limits of balance or the target location is likely to bring about errors during reaching. Attempting to reach for objects that are beyond reach requires either reestablishing standing balance within the current base of support or stepping to create a new broader base of support, a strategy that is not always possible or successful. Age-related declines in sensory acuity could therefore result in misjudgment and an attempt to reach a target beyond reach. Exacerbating the problem, the reduced sensorimotor function of many older people makes them less able to restore balance if they overshoot so that falling is a more likely outcome. Thus, it has been proposed that an overestimation of ability, rather than physical ability, could be an important etiological factor for falls among older people (4,5).

This large prospective cohort study of older people examines the maximal distances they can lean forward without losing balance and compares these with the distances that they will attempt to reach and anticipate success. Our hypothesis is that poor physical ability will be associated with prospective fall rates but, independent of this physical risk, those who misjudge and overestimate their abilities are also at risk of falls, and this will also be reflected in their fall rates.

METHODS

Participants
Participants (N = 415) aged 70–90 years were recruited initially by random selection from the State Electoral Roll of Sydney’s eastern suburbs after excluding respondents
REACHING AND FALLS

with neurological, cardiovascular, or major musculoskeletal impairments. Attrition was eight participants who did not complete follow-up through withdrawal, illness, or death. All lived in private households. Initial screening by the mini mental state examination (6) excluded participants with significant cognitive impairment; included participants scored ≥24 (28.0 ± 1.5 SD).

The study was approved by the Human Research Ethics Committee of the University of New South Wales and conducted in accord with the Declaration of Helsinki. All participants provided written informed consent.

Design
This prospective cohort study investigates the association between reaching judgment error, maximal reach, and 1-year retrospective and prospective falls.

The maximal distances that participants were prepared to reach forward while standing were determined and compared with their actual maxima to estimate reach judgment errors.

Attempted and Maximal Reach
Participants were asked to judge the furthest distance they could reach to retrieve a broomstick (Figure 1). To begin, the stick hung from a horizontal pole attached to the ceiling of the laboratory, 120 cm beyond the front of the feet, a distance known to be beyond the reach of everybody. It was made clear that the stick hung from a weak string and could freely slide along the length of the pole but could not be used for support. Visual cues in the laboratory were kept constant across all participants.

At this initial distance, participants stood with their arms by their side and were asked if the stick was at the furthest distance they would be able to lean forward, retrieve the stick and return to their standing position. They were allowed as much time as necessary, without practicing, to make this judgment. If they thought they could not retrieve it, the experimenter brought the stick 5 cm closer and the process was repeated until they stated that they would be able to retrieve the stick and it was the furthest distance they could reach. Participants were then asked to retrieve the stick at their chosen distance. The distance from the front of the feet to the stick was recorded using a tape measure not visible to the participant. They were not aware that they had to attempt their estimated maximal reach distance until after they made their decision.

The stick could be grasped at any height. There was no restriction on the method to retrieve the stick, except that the stick could not be swung and grasped on its return. This ensured that the person was able to plan and estimate their reach in a way that would be familiar. If any restrictions were imposed, it would lead to an estimation of ability in an unfamiliar task.

After the attempt to reach from the step, maximal reach was determined from floor level by moving the pole 5 cm closer until success or moving it 5 cm further away until they failed if they had succeeded. This provided a most distant successful reach and a closest unsuccessful reach from which a maximal reach was assigned by linear interpolation. Linear interpolation was used because reach distances were made at 5 cm intervals so that the true reach distance was somewhere between the maximal stick they could reach and the next 5 cm interval. This gives an unbiased measurement.

The initial participants (n = 124) judged their reach standing at ground level. After observing them, we had the remaining participants (n = 291) make the judgment while standing on a low (20 cm high) stable platform to force a more considered judgment of ability and prevent them creeping forward across the baseline. On final analysis, however, attempted reach distances relative to actual maxima were not significantly different between those who attempted on the floor and on the raised step (attempted reach = 83.0 cm ± 0.9 vs 82.5 cm ± 0.6, F1,415 = .24, p = .62; error = −5.3 cm ± 0.7 vs −4.6 cm ± 0.5, F1,415 = .74, p = .39) and all participants were included in the analysis.

Corrected binocular visual acuity was assessed using a logMAR chart, measured as the minimum angle resolvable in minutes of arc [MAR; (7)]. Contrast sensitivity was assessed using the Melbourne Edge Test measured in decibels [dBs; (8)]. Physical activity was measured (both incidental and planned) using a questionnaire (9).
Falls Monitoring

Prospective falls, using the definition of Gibson and colleagues (10), were monitored with monthly return-mail calendars for 12 mo after reach testing. One-year retrospective falls incidence was obtained at initial assessment. Only falls stated to be caused by clear cardiovascular aetiology were excluded. The location of the fall and injuries were recorded.

Analysis

Body morphology (height, arm length, and weight) as predictors of actual reach were explored by stepwise multiple linear regression and the β-weights were used to calculate adjusted normalized reach distances to reflect relative performance. For each participant, error was calculated as the difference between the attempted (ie, perceived maximum) and the maximal reach distance. As the relative error is not as great for a person with a long reach, judgment error was normalized as a proportion of maximum reach (4).

One-way and repeated-measures analysis of variance with Bonferroni correction were used for parametric comparisons. Pearson’s correlation coefficients were used to examine the relationship between variables. Associations were seen to be nonlinear and so participants were divided into four groups for judgment errors (cautious to excessive) and quartiles for maximal reach. Binary logistic regression determined odds ratios (standardized regression coefficients) for the association between maximal reach and prospective and retrospective falls. Proportions were examined by χ² test. To assess whether judgment error, and the interaction between judgment error and maximal reach associated with falls, an analysis of variance was used with maximal reach distance and judgment error (quartiles) as independent variables and falls as the dependent variable. Statistical significance was set a priori at p < .05.

Results

The results presented here first consider the relationship between reaching ability, reaching decisions, and then how ability and reaching decisions are associated with falls.

Mean age was 77.3 years (± 4.5 SD), 185 were male and 230 were female. The mean visual acuity for the group was 1.5 (± 0.5) and edge contrast sensitivity (dB) 19.9 (± 2.2).

Factors Affecting Maximal and Attempted Reach

The mean maximal distance reached for the group was 87.4 cm ± 8.0 (SD) and men could reach further than women (90.6 cm ± 0.6 SEM vs 84.9 cm ± 0.5; F₁,₄₁₄ = 56.8, p < .001). Increasing age was associated with poorer reaching ability (r = −.27, p < .001).

Stepwise multiple linear regression showed significant effects of height (standardized β-weight = .40, p < .001) and arm length (β = .24, p = .001) with no independent effect of gender or weight. Thus, a normalized reach was calculated from the regression coefficients to reflect relative performances between participants. Maximal reach from this point forward will refer to the normalized maximal reach measure.

For the following analysis of reach judgment and falls, participants were divided into quartiles (n = 103–104) based on their maximal reach: best performers (95.1 cm ± 0.3), good performers (90.1 cm ± 0.3), moderate performers (85.8 cm ± 0.3), and poor performers (78.6 cm ± 0.3).

The mean attempted reach for the group was 82.7 cm ± 9.7 (SD). Once participants had estimated their maximal reach, no one altered their decision when asked to attempt to retrieve the stick. Men estimated their reach as further than women (85.3 cm ± 0.7 SEM vs 80.6 cm ± 0.6; F₁,₄₁₄ = 25.1, p < .001) but after adjusting for height and arm length as described earlier, there was no difference (82.5 cm ± 0.7 vs 83.0 cm ± 0.6; F₁,₄₁₄ = .51, p = .47). Older people attempted shorter reaches compared with younger elderly people (r = −.16, p < .001). Attempted reach from this point forward will refer to the normalized attempted reach measure.

Judgment Errors

On average, the distances participants attempted to reach were shorter than their actual maximal reaches (normalized 82.7 cm ± 0.4 vs 87.4 cm ± 0.3, respectively; F₁,₄₁₄ = 156.3, p < .001). Only 15.2% of participants attempted to reach for a pole that was beyond their maximal reach.

Errors in judging reach distances varied across a range of about 30% of maximal reach distances and followed a Gaussian distribution (Figure 2). Participants were classified according to whether their attempted reach was excessive (15.2%), exact (<3% error, 17.3%), safe (3–10% error, 44.8%), or cautious (>10% error, 22.7%).

Figure 3A shows that across this population, the attempted reach (ie, judgment) contributed to the error in the
There was a main effect of visual acuity across the reach judgment error groups ($F_{3, 412} = 3.2, p = .02$) but after Bonferroni correction, this effect was not significant. Visual contrast sensitivity did not differ between the judgment error groups ($F_{3, 412} = 0.91, p = .44$).

There were no differences in cognitive function (as assessed by mini mental state examination) among the different reach judgment error groups ($F_{3, 412} = 1.4, p = .25$).

Reach and Falls

On initial assessment, 33% of participants reported that they had fallen at least once and 14% at least twice in the past year. In the 12 mo following testing, 46% of participants fell at least once and 22% at least twice. Of these prospective fallers 70% sustained at least one injury, 18% ($n = 33$) required medical attention, and 7% ($n = 14$) reported a fall that caused a fracture.

There were no significant differences in the fall rates of men and women (retrospective 30% men vs 35% women, $\chi^2 = 0.21, p = .61$; prospective, 45% vs 48%, $\chi^2 = 0.51, p = .48$).

Maximal reach was a statistically significant predictor of 1-year retrospective (odds ratio = 0.93; 95% CI, 0.89–0.97) and prospective falls (odds ratio = 0.96; 95% CI, 0.93–0.99).

Fall rates were also analyzed with participants grouped by reach performance. For the retrospective report of falls at entry, the incidence of single falls and multiple falls increased with poorer reach performance (Figure 4A). The effect was not clear in the prospective data. However, it should be noted that the reported retrospective rates are significantly smaller than the prospective rates (33% vs 46%; $\chi^2 = 38.4, p < .001$). Those who had the best reaching ability had a different profile to the other reach groups, reporting a very low fall rate prospectively and a disproportionately higher incidence prospectively.

The effect of reach performance is more pronounced when considered as mean falls per person (Figure 4B; retrospective data $F_{3, 412} = 4.6, p = .003$; prospective $F_{3, 404} = 2.8, p = .038$). Again, mean falls per person were significantly less when reported retrospectively rather than prospectively, $0.55 \pm 0.05$ vs $0.99 \pm 0.08$; $F_{1, 406} = 35.4, p < .001$).

Judgment errors and falls.—Misjudgments of reach showed no significant linear correlation with 1-year retrospective ($p = .76$) or prospective fall rates ($p = .59$). There were no significant differences for the incidence of falls, single, or multiple, among participants grouped by judgment error (Figure 5A; retrospective and prospective, $p = .19–.92$) or for the fall rates per person among these groupings (Figure 5B; $p = .26–.41$), although there is an indication that the exact group tend to have fewer multiple falls.

In an analysis of variance with maximal reach distance and judgment error (quartiles) as independent variables, and falls as the dependent variable, there was no significant effect of judgment error on prospective falls ($F_{3, 404} = 0.39,$...
There was no significant interaction between judgment error and maximal reach (F\(_{3,404}\) = 0.31, p = .81). Further analysis of the link between judgment error and prospective falls that resulted in injury or fracture, falls that required medical attention, or falls that occurred indoor or outdoor revealed no significant association.

Participants, who are more physically active fell significantly less, had a higher maximal reach and were more likely to estimate their maximal reach the same as their actual maximal reach (exact group) p < .05.

**Discussion**

Reaching requires continuous monitoring and adjustment of posture and balance. People overestimate their reach when they are not standing or posture is restricted (11–16), reflecting a misperception of body schema. During standing, when a large component of reaching involves leaning, perceived reach distances are generally less than actual (5,15). In a more complex task that required reaching for a moving target, older participants were less likely to approach the limits of balance (17). An explanation for these observations is that for complex and novel actions that are not familiar, there might not be a readily available internal model to plan the action. Thus, people are likely to have a current internal model from which they make a considered judgment of their reaching distance. For this reason, the unrestricted reaching method used to measure judgment in the present study is based on each person’s own method of reaching and was chosen because it is the common way to reach.

Across the population, people attempted shorter reaches as physical performance declined. This could suggest that older people compensate for lost function. However, when considered relative to reaching ability, attempted reaches show that people either under- or overcompensate for lost function and few accurately estimate their reach.

**Ability**

The association between poor functional reach and physical frailty has been reported previously (18). The functional base of support decreases with age through loss of strength and balance and this reduces the maximal distance older people can reach and lean without stepping (1,2).

**Physical ability and falls.**—Physical ability and sensorimotor performance are associated with falling among older people (19–21). Among older people, a significant number of falls (17%) are reported to occur during overreaching or leaning (22). One test of reach, termed “functional reach,” is
measured as the difference between arm length and the maximum distance a person can reach forward. It is used as a measure of balance and is reported to predict falls (3,23).

Across the large cohort of older people studied here, unconstrained reaching ability after correcting for body morphology was significantly associated with both retrospective and prospective fall rates, which agrees with some studies (3,24–25). Some studies have found no association (25–28). However, the dynamics of the reach task in this study are more complex than those associated with the functional reach task used in the other referenced studies. Also, sample sizes and type of fall reports vary. This makes it difficult to compare these studies.

In this, the reaching task in this study joins a range of other physiological measures that reflect balance control and are known to predict falls in this population (19–21,29).

**Functional Associations With Judgment Errors**

The group that overestimated their reach (excessive group) had the poorest reaching ability. The group that were exact in judgment showed the best performance.

**Physiological factors.**—Robinovitch and Cronin (5) showed no significant difference between the perceived and actual reach of older women, suggesting that overall they judge ability accurately. However, younger women significantly underestimated their reach when standing. Thus, relative to the younger, older people are prepared to overextend their reach. Older people who have impaired balance overestimate the distance they can reach (5,30). People with Parkinson’s disease are more likely to overestimate their reach and this increases with disease progression (31). This also applies to people with poor executive function and after stroke (4,32). Thus, older people and especially those with impaired balance control could lack a potential “safety factor” observed in young people (5).

Ability declines with age over many aspects of sensorimotor function (33). Although older adults had a shorter reach and attempted shorter distances, age did not differ among the judgment error groups. Thus, despite the age-related declines in attempted and maximal reach, age alone does not predict judgment ability.

**Risk Taking?**

Leaning closer to the limit of the base of support increases the probability of losing balance so that part of deciding on a reach distance that would be attempted could be based on the risk a person will accept.

**Is reaching risky?**—In reaching for an object, the action is normally guided by an established forward internal model that relies on sensory information of the body’s state and the target location (34). As sensory function is lost, the precision of this estimation and control is compromised. Older people show a greater tendency to use sensory information from moment-to-moment in a feedback mode of control to compensate for impaired forward estimates (35–37). Loss of sensorimotor function is detrimental to precise feedback control and execution of the reach. However, it will introduce an intermittent and hesitant reach, where repeated reassessment provides an option of withdrawal if the target cannot be attained.

These considerations suggest that attempted reach assessed by this and similar protocols are not risky as it is possible withdraw without penalty. The limits of balance are encountered only within the last centimeter or so. Until the boundary of stability, the action is monitored and reassessed and the person can be confident of regaining their balance if needed. The task does not commit the person to the action because there is always the opportunity to retreat. The option of stepping from the small height tested here if they overbalanced was not perceived as a hazard for most. Of the 15% of older people who failed on attempt, none fell as they reached. Most simply failed to reach the target and resumed their original standing posture and a couple regained balance by stepping forward.

Balance control is altered when standing at heights and is reported as a “stiffening” that is thought to reflect fear (38). If there was an element of risk, reaching behavior should have been different when participants attempted reaching from the raised platform as compared with standing on the floor but the same mean attempted reach was observed in the two protocols. We investigated this with an experiment on a group of seven younger people, having them nominate maximal reach distances and reach from the edge of platforms of different heights (35 and 115 cm). Even at heights at which stepping was not an escape option as falling was a real hazard, there were only small reductions in attempted reach distances relative to the sensitivity of measuring active reach. At the significant height of 115 cm, attempted reach was reduced by only 1.25 ± 0.92 cm (SEM) relative to the 35 cm platform.

**Reach Judgment Errors and Falls**

It has been proposed that awareness of postural and balance limits and reach judgment errors could have a causal association with falls through a mechanism of overestimating balance ability and poor motor planning (5,17,22,39). One 3-mo prospective study of 88 older people suggests a possible effect with post hoc analysis (30). The results of the present large prospective cohort study do not support this hypothesis.

**Reporting Falls**

The large proportion of fallers in this study is higher than typically reported. Most commonly fall rates in older people are reported as ~33% (21,40). The fall rates reported in our study are higher but are consistent with other large
prospective studies (41–43). These recent studies may reflect a change in fall rates among older people.

It is worth noting the different pattern of falls reporting. One-year prospective fall rates were significantly higher than retrospective rates. This is most likely due to the measurement of falls. Retrospective falls are recorded using a single question at initial assessment and this relies on accurate memory and falls may be forgotten (44). Prospective falls measured with monthly falls calendars or similar results in the higher reporting rate. People with the best reaching ability in this study reported two and a half times as many falls during the follow-up year than during the previous year (five times as many for multiple falls), a much higher proportional increase than the poorer performers. The reasons for this are unclear but it is possible that they do not recall retrospective falls because their effect was minimal or expected in context of the activity. The best performers are likely to have a more active life that results in falls that are forgotten unless monitored regularly. The association between physical activity and falls has been shown to have decreases or increases in fall rates (45). In this study, people who were more physically active had lower fall rates, despite the greater exposure risk for falls.

Limitations

Method.—It is possible that the measurements of maximal reach and attempted reach are biased as both measurements had to be performed in the same setting. Perceptions of what can be achieved measured in a setting that is different from that used in measuring actual performance can minimize the effect of the estimated on actual performance. In this study, participants were not aware that they had to attempt their estimated reach distance until after they made their decision. All participants attempted to retrieve the stick at their chosen distance and none altered their estimate before their attempt. However, it remains possible that some participants intentionally failed farther reaches to justify the accuracy of their prediction.

Cognitive impairment.—This study was designed to look at behavior in cognitively intact older people. It is important to understand behavior among older people without cognitive impairment before looking at those with cognitive impairment. Cognitive impairment (as assessed by mini mental state examination) was not associated with reach judgment errors. However, people with significant cognitive impairment were excluded from this study. This test may be useful as a predictor of falls in people with cognitive impairment who may fall due to impaired executive function, risk taking, and impulsiveness.

Conclusions

This study compared decisions and ability to undertake a reaching task that in the real world could be potentially risky if there is an error of judgment. Maximal reach reflects sensorimotor function in older people and here was associated with a lower incidence of falls.

People who can reach the furthest, allowing for body anthropometrics are also those who accurately judge their ability to reach. Most poor reachers overestimated their maximal reach and fewer judged exactly. There was no association between reach judgment error and falls. It appears that reaching, as presented in studies of this type is not a significant risk so that it is not possible to make specific conclusions about risk-taking behavior, decisions, and falls.

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References


