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BALANCE AND FALLS IN ELDERLY PEOPLE: MECHANISMS AND MANAGEMENT*

Nicola R. Colledge†, Geriatric Medicine Unit, Royal Infirmary of Edinburgh

Falls in old age are a major cause of morbidity and mortality and often herald the loss of an old person's independence. Each year approximately 30% of people over 65 years will fall, with around half having recurrent falls.[1–3] About 10–15% of falls result in serious injury[3,4] of which hip fracture is the most important. In Scotland, 77% of deaths due to accidents in the home in people aged over 65 years are accounted for by falls.[5] Among those aged over 75 years in Scotland, falls resulted in 200 deaths, nearly 5,000 hospital admissions and 13,500 new out-patient visits in 1991.[5] As only 25% of elderly people who fall seek medical help, there are likely to be approximately 1 million falls in the home each year in Scotland.

Although only 10–15% of falls result in serious injury, the psycho-social impact of even a minor fall should not be underestimated. The anxiety caused by fear of falling and/or being unable to rise can result in loss of confidence and self-imposed restrictions on activities. Fall survivors experience a greater decline in activities of daily living and in physical and social activities than non-fallers,[6,7] and have a greater risk of institutionalisation.[8] The costs associated with falls and fall injuries are also high. It has been estimated that $3·7 billion was spent in 1984 in the USA on people aged over 65 years with unintentional injuries, the majority of which were due to falls.[9]

While much work has been done on the natural history of falls, our understanding of the effects of ageing on the basic neuromuscular mechanisms involved in postural control is limited. Investigation in this area has the potential to unravel the complex physiological abnormalities responsible for poor balance in old age and to indicate possible therapeutic and preventative measures.

NORMAL BALANCE

The upright human posture is inherently unstable. Complex neuromuscular homeostatic mechanisms have evolved in order to maintain posture. Afferent sensory inputs include vision, proprioception and the vestibular system which convey information about the position of the body in relation to itself and the environment. There are linked anticipatory reflex pathways which have an important role in maintaining stability by activating proximal muscles during specific postural tasks. The integration of exteroceptive and interoceptive information occurs predominantly at reflex level. The postural reflexes are organised hierarchically with the lowest level being the spinal stretch reflex system which has a very short latency of 40–50 ms. The next is the long latency automatic postural response system, which begins in muscles closest to the base of support and spreads proximally in a stereotyped pattern. At the highest level, processing occurs centrally in the brain; a number of sites are involved but particularly the cerebellum, brain stem and basal ganglia. This central processing leads to a complex output of postural motor responses which are conveyed via the spinal cord and peripheral nerves to limb and trunk muscles.

Assessment of the contributions of the various sensory and motor factors to the maintenance of posture is not straightforward. This is because the system has a high level of redundancy. For example, if vision is eliminated by placing a subject in the dark, proprioceptive and vestibular systems can provide sufficient sensory information to maintain balance. This makes it difficult to interpret problems with balance and to predict the deficit produced by a specific sensory or motor problem. It also makes it difficult to establish the effects of ageing on balance.

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†Senior Lecturer and Honorary Consultant.

AGEING AND BALANCE

An age-related increase in postural sway with healthy ageing was first documented in 1963 by Sheldon,[10] and this has been confirmed on many occasions since[11–15] (Fig 1). The cause of this increase is much debated—is it due to a single mechanism or the summed effects of ageing on several systems? It is well known that peripheral sensory function deteriorates with age; older people have higher proprioceptive thresholds to passive movement[16] and are less accurate at reproducing and matching joint angles.[17] Anatomical changes have been noted in the semicircular canals, utricle and saccule of the vestibular system with increased age[18,19] but the effect of these on vestibular function is unclear.[20] Visual acuity also declines with age,[21] as does visual contrast sensitivity[22] which may be particularly important in postural control.

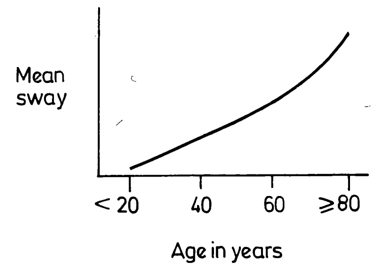

FIGURE 1

The increase in postural sway with age.

As regards central processing and integration, there is evidence that both reaction times and muscle activation times increase with ageing.[23] In addition, longitudinal studies of motor function have shown that muscle strength and power decline with normal ageing.[24] Given all these changes, it becomes hard to understand how the elderly remain upright at all.

Balance can be measured quantitatively by a number of means. Early work used Wright's ataxiameter which was first described in 1971.[25] It consists of a box from which a taut thread extends and is attached to a belt around the subject's waist. The other end of the thread is attached to a perforated wheel within the instrument. Each time the wheel is rotated through an angle of 3·5°, a light beam is cut and a count is registered. Sway is expressed as total angular movement, regardless of sign, in the antero-posterior plane only. Alternative methods measure sway in all directions. Sway magnetometry measures hip movement in the sagittal and coronal planes via magnetic field detectors worn at the waist.[26] However force platforms are now more commonly used. These measure the movement of the body's centre of gravity. The apparatus consists of a metal plate with load cells under its four corners. When a subject stands on the platform, the load cells generate electrical charges which are converted into voltages. These are fed into a computer which produces a vector that describes the movement of the subject's centre of gravity. The subject simply stands on the platform and changes in the position of his/her centre of mass are monitored over a set time period. Such systems have confirmed the increase in spontaneous sway that occurs with ageing,[12,13,15] and have been used in an effort to unravel the predominant cause for this. The sensory systems have been examined by measuring sway with and without vision and with altered proprioceptive input, by standing subjects on a foam instead of a firm surface.

Using such a system, we found that sway increased when vision was removed, and increased further when subjects stood on foam. However, the relative contributions of vision, proprioception and the vestibular system did not change with ageing.[15] Dependence on vision was measured by calculating the Romberg quotient (sway with eyes open/sway with eyes closed), and dependence on proprioception by calculating the proprioceptive quotient (sway on a firm surface/sway on a foam surface). The lower the value of the quotient, the more dependent is the subject on that input for postural stability. It was found that there were no significant changes in either quotient with increasing age. If the age associated increased in sway were due principally to loss of visual acuity, there would be an increased dependence on proprioception, with higher Romberg quotients and lower proprioceptive quotients. Likewise if proprioceptive loss were more significant, dependence on vision would have increased with lower Romberg quotients and higher proprioceptive quotients. One explanation for the demonstrated lack of change in the contributions of vision, proprioception and the vestibular systems to balance is that they all deteriorate to an identical extent with ageing, but this seems inherently unlikely. It is much more likely that the increase in sway associated with ageing is not due to loss of peripheral sensation but more to slowing of central integration or the effector response.

Others have confirmed that this is likely to be the case. The absolute latencies of distal muscle responses are greater in older than younger people, when their balance is disturbed unexpectedly by movements of the support surface on which they stand.[27–30] Stelmach found that such delays are more marked in response to small-slow movements of the support surface which require higher level sensory integration than large-fast rotations which activate long-loop reflexes,[28] adding further evidence that elderly people are at a disadvantage when posture is under the control of slower, higher level sensory integrative mechanisms.

A loss of the correlation between the muscle responses in agonist and antagonist muscle groups in older people has also been found.[31] In younger people, only the agonist muscles respond in response to a platform displacement, allowing a corrective movement to occur. In older people, the antagonist muscles also respond on a significant number of occasions, causing the joint to stiffen with the result that no corrective movement can take place.

Further studies have compared sway in younger and older people when they are presented with conflicting sensory data.[27,32–34] This has been performed

using dynamic posturography in which both the support surface and visual surround can be 'sway-referenced' i.e. the system can be programmed so that the support surface and visual surround will sway with the subject, thus giving inaccurate proprioceptive and/or visual data. These studies have confirmed small differences between young and old under conditions that do not stress balance,[33] but demonstrated a much greater disparity under conditions with limited sensory input,[32–34] and greater yet with distorted sensory input.[32–34]

When faced with sensory conflict, higher levels of central integration become necessary to resolve the conflict, which in turn, requires greater processing. These findings again suggest that integration and processing are slowed with ageing, and that such changes are the cause of the deterioration in balance in older people.

Stelmach has reinforced the importance of the slowing of integration and response times in the causation of falls. If postural instability goes uncorrected, a critical time boundary is soon exceeded beyond which balance cannot be recovered. This time boundary has been estimated at 280 ms. If ageing has the effect of even a moderate slowing of response selection, then a large increase in the number of falls could result: for instance if a 10% increase in mean response time is assumed to occur with ageing, then the number of critically slow responses (and thus falls) could increase by almost 600%[35] (Fig 2).

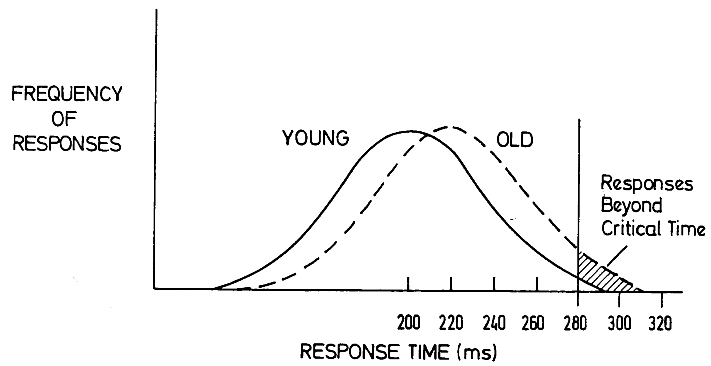

FIGURE 2

Hypothetical distributions of response frequencies for young and old showing the effect of a small age-related change in response time.[35] (Reproduced with permission of W.B. Saunders Co.)

In studies that exclude subjects with age-related diseases associated with impairment of sensorimotor and joint function, it is noteworthy that differences in sway across the age groups are not prominent.[34,35] This suggests that severe balance dysfunction associated with impaired mobility and frequent falls may be less a function of age and more the result of disease. This is supported by studies of frail nursing home residents who were found to have profoundly impaired balance.[36,37] The magnitude of these deficits was much greater than those seen in the healthy elderly subjects, thereby supporting the importance of age-associated diseases such as stroke and Alzheimer's disease, and drugs such as hypnotics or sedatives in producing the balance impairment underlying muliple falls.

FALLS AND BALANCE

Clearly we are some way from fully understanding the physiological mechanisms underlying the changes in postural control that take place with ageing. But how do these changes in balance relate to falling?

Overstall was one of the first to demonstrate that sway is significantly greater in individuals with a history of falls than those without.[11] Of note is the fact that this was only the case for those who reported loss of balance or giddiness, and not for those who fell because of tripping. This has been confirmed in numerous subsequent studies using a variety of measurement techniques.[14, 38–42]

More recent work has focused on the use of balance measurement to identify elderly people at risk of future falls, in the hope that balance tests could find a clinical application in screening and targeting of high risk individuals for preventative intervention. Prospective studies of falling are inevitably difficult to perform. Results will vary depending on whether a population at low or high risk of falls is selected, and follow up may be difficult and dependent on the subject's reliable recall of falls. There is also the problem of how to assess balance. Some studies have focused on recording sway by posturography,[43–48] while others have relied on simple clinical tests (e.g. timing and/or rating ability to balance on one leg or to perform manoeuvres such as turning or standing up).[3, 4, 49] The advantages of clinical tests are that no equipment is required, but although inter-rater reliability may be excellent in a research setting, it is less certain that this would be the case in usual clinical practice.

Despite these difficulties, most studies have demonstrated that falls can be predicted by balance measurements[3, 4, 43–50] and that posturographic testing of balance is a more powerful predictor of falling that clinical assessment.[50] It should be noted however that, taken alone, balance measurement can only determine the risk of future falls with moderate accuracy.[50] It is much more useful when used as part of a battery of tests for predictive risk factors. Different approaches have been taken in the development of such batteries. Some have concentrated on the physiological systems involved in postural control, with detailed assessment of visual acuity and contrast sensitivity, vibration, proprioception, limb strength, and reaction time as well as more global tests of balance.[46, 48] Such a battery correctly identified 75% of women aged over 65 years who fell more than once in the subsequent year.[48] Others have used a variety of demographic, medical and social factors known to be associated with falls. Tinetti has devised a risk factor index for falls which includes sedative drug use, cognitive impairment, 'foot problems', 'disability of lower extremity' as well as abnormalities of balance and gait.[49] It was found that the risk of falling increased linearly with the number of these risk factors present from 8% with none, to 78% with 4 or more. Surprisingly, the number of environmental hazards was not significantly associated with falling in this study. This may reflect the fact that individual frailty is more important than home circumstances.[49] Clearly, the most useful risk factor batteries are those in which the risk factors identified are amenable to intervention.

Work published on the prediction of osteoporotic fractures has provided further evidence for the importance of balance;[51] in Dubbo in New South Wales 46 per cent of the town's citizens aged over 60 were screened for potential risk factors including height and weight, reproductive history, calcium intake, alcohol and tobacco consumption, bone mineral density, and also quadriceps strength, tactile sensitivity and body sway. Over the next three years, all fractures were identified by reviewing the X-ray reports in the only two radiology services available locally. The study found that bone mineral density, muscle strength and sway were independent and powerful synergistic predictors of fracture incidence.[51] There has been some criticism of the statistical methods used but the implications of these findings are important. Fractures require an injury as well as reduced bone mineral density, and such injuries are most likely to occur in those with poor balance and strength. It also implies that interventions to improve strength and sway could ultimately reduce not only falls but fracture rates.

IMPROVING BALANCE

So, can balance be improved in old age, or is its deterioration an irreversible process? That it can be improved is suggested by the studies described above which examined responses to unexpected movements of the support surface on which subjects are standing. It was found that the sway of elderly subjects improved with repeated presentations of the same movement, and that this improvement was greatest when the initial performance was poorest.[33]

Work to date suggests that training programmes designed to specifically improve the function of a single system such as muscle strength or the vestibular system are generally more effective than training programmes with a more global approach. Controlled trials of 12 and 16 week general exercise classes that included breathing exercises, one and two leg standing, stretching and strengthening and relaxation exercises as well as reaction time exercises and walking trials failed to show an improvement in balance among frail older women.[52, 53]

Training programmes directed toward specific physiological systems related to postural control have consistently reported significant training effects. Fiatorone used an 8 week training protocol of leg muscle strengthening exercises with progressively increased external loads among 90 year old people.[54] Significant improvements in muscle strength and clinically assessed balance were found. Ledin reported a positive training effect among older people using a 9 week exercise programme with a particular emphasis on vestibular habituation.[55] The tasks included jumping, walking on toes and heels, walking with sudden turns, standing on one leg with eyes open and closed, visual fixation during neck movements and trampolining. Hu and Woollacot found improvements in sway in subjects aged 65–90 years who had undergone a 10 hour training session in what they termed multisensory training.[56] This involved practising balance in eight increasingly difficult conditions from standing on a firm surface with eyes open and head neutral to standing on a foam surface with eyes closed and head extended.

Improved balance and falls

The studies detailed above used a measured improvement in balance as their outcome, rather than any effect on subsequent risk of falls. Clearly the latter is of paramount importance, as it could be argued that the improvements gained might be insufficient to prevent falls, or that the gains were short term only. Given that falls are generally related to multiple risk factors amongst which balance on its own has only a moderate predictive ability, it would be very difficult to show that improved balance alone led to a reduced fall rate. Multiple interventions are likely to be required, and a number of controlled trials have addressed this. Two such trials used unfocussed 'rehabilitation' which we now know would be unlikely to improve balance, and indeed neither trial showed any significant reduction in falls.[57, 58]

In an effort to understand the effect of exercise and balance training on falls prevention, the National Institute on Aging and the National Institute for Nursing Research jointly sponsored a multicentre study called Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT).[59] This was a collection of eight independent clinical trials that assessed the efficacy of a variety of intervention strategies, including exercise, in preventing falls in the elderly. The trials were conducted at different clinical centres on different clinical populations, using different interventions for different periods of time, although exercise was a component at all sites. Follow up for falls continued for 2–4 years. Many of the outcomes and baseline variables were common to all sites and were measured using the same instruments and protocols. This allowed pooling of the individual FICSIT results so that the effect of exercise could be measured with greater power than would be achieved by a single trial.

The pooled results revealed that interventions which included exercise were associated with a significantly reduced risk of falling, and those that included balance training were particularly effective and more so than those that included strength, flexibility or endurance training.[60] No reduction in falls-related injury was demonstrated.

The authors explain these findings by suggesting that balance deficits may have a more direct causal pathway in the generation of falls than strength, flexibility or endurance deficits. In addition, subjects may be more aware of limitations in the latter three as these may manifest in activities of daily living which do not of themselves cause falls. On the other hand, balance deficits are likely to be manifested literally as loss of balance with or without a fall. Therefore balance training may work not just because it improves stability, but because the subject becomes more aware of his/her limitations and makes more allowance for these.[60]

A further controlled trial has been reported of a multiple risk factor intervention strategy, which included an aggressive balance and strength training programme.[61] Three hundred and one men and women living in the community who were at least 75 years old and who had a least one risk factor for falling were studied. Tinetti reported a significant reduction in the rate of falling over the subsequent year from 47% in the control group to 35% in the intervention group. The study also documented a significant improvement in clinically assessed balance, transfer skills and gait as a result of the training programme. The programme included the performance of four levels of progressively more destabilising maneouvres with decreasing amounts of support. Subjects were instructed to perform these exercises twice daily for 15–20 minutes. Unfortunately, the paper detailing the treatment protocol provides only a very poor description of these exercises.[62] Other risk factors assessed and dealt with in the study group included postural hypotension, sedative use, use of 4 or more prescribed drugs, reduced arm or leg strength, and environmental hazards.

This study was much more intensive than any previously reported and involved a mean of 7·8 visits to subjects' homes by both a nurse and a physiotherapist and subsequent liaison with their primary physician. Control subjects were visited a mean of 6·2 times by social work students. The estimated cost of the programme per fall prevented was $1,947. For a fall requiring medical care the expenditure was $12,392 whereas the actual cost of medical care was estimated at $11,891, suggesting that a more cost-effective approach needs to be identified. This might include the targeting of a higher risk population, and/or identifying less labour intensive interventions. Nonetheless, the hidden psychosocial costs of falls such as anxiety and self-imposed restriction on activities should not be forgotten and if this trial can be replicated, it will be a major contribution to public health.

SUMMARY

Our understanding of the effects of ageing on balance is improving rapidly. It is generally agreed that the balance impairment that occurs with healthy ageing is due to slowing of central integration and processing. These age related changes are further compounded by disease and drugs, so that the frail elderly are more likely to fall than their healthy contemporaries. Age related changes in balance are not irreversible even in the very old, and can be improved by specific training programmes. Evidence is also emerging that falls can be prevented by using such programmes in tandem with intervention for other risk factors. It remains to be seen whether these programmes are also effective in preventing fractures.

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