

A Physiological Profile Approach to Falls Risk Assessment and Prevention

The purpose of this perspective article is to describe the use of a physiological profile approach to falls risk assessment and prevention that has been developed by the Falls and Balance Research Group of the Prince of Wales Medical Research Institute, Sydney, Australia. The profile's use for people with a variety of factors that put them at risk for falls is discussed. The Physiological Profile Assessment (PPA) involves a series of simple tests of vision, peripheral sensation, muscle force, reaction time, and postural sway. The tests can be administered quickly, and all equipment needed is portable. The results can be used to differentiate people who are at risk for falls ("fallers") from people who are not at risk for falls ("nonfallers"). A computer program using data from the PPA can be used to assess an individual's performance in relation to a normative database so that deficits can be targeted for intervention. The PPA provides valid and reliable measurements that can be used for assessing falls risk and evaluating the effectiveness of interventions and is suitable for use in a range of physical therapy and health care settings. [Lord SR, Menz HB, Tiedemann A. A physiological profile approach to falls risk assessment and prevention. *Phys Ther.* 2003;83:237-252.]

Key Words: *Accidental falls, Aged, Assessment, Balance, Muscle force, Physical therapy, Reaction time, Vision.*

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One of the major problems associated with aging is an increased susceptibility to falling.¹ One in 3 older people living in the community are likely to fall one or more times in a year,²⁻⁴ and rates of falling are even higher in older people living in intermediate and nursing home care facilities.⁵⁻⁷ One quarter to one half of all falls among community-dwelling older people result in injury, 10% to 15% of falls are associated with serious injuries, 2% to 6% of falls are associated with fractures, and approximately 1% of falls are associated with hip fractures.⁸⁻¹⁰ The most commonly self-reported injuries include superficial cuts and abrasions, bruises, and sprains. The most common injuries that require hospitalization are femoral neck fractures and other fractures of the leg; fractures of the radius, ulna, and other bones in the arm; and fractures of the neck and trunk.¹

Many researchers^{1-3,11} have attempted to identify risk factors for falls and to develop strategies for prevention. Older people (ie, those aged 65 years and over) with multiple chronic illnesses have higher rates of falls than active older people without known pathology or impairments.^{1-3,11} Stroke,^{2,3} Parkinson disease,¹² a history of falls,^{2,4} the presence of impaired gait,¹³ muscle weakness,⁴ arthritis,^{3,11} foot problems,^{2,14} impaired cognition,^{2,11} abnormal neurological signs,¹¹ and the taking of psychoactive medications⁶ and multiple medications⁶ have been shown to be important predictors for falls. However, attributing a degree of falls risk to a specific medical diagnosis is problematic because the relative severity of the above conditions may vary considerably among individuals. Furthermore, declines in sensorimotor function associated with age,¹⁵ inactivity, medication use, or minor pathology may be evident in older people with no documented medical illness.

In response to this problem, we have taken a “physiological” rather than “disease-oriented” approach to evaluating falls risk factors, an approach that deals with impairments irrespective of their cause. This approach involves direct assessment of sensorimotor abilities rather than documenting the presence or absence of a diagnosed disease. For example, in an older person with cataracts and associated visual impairment, the identified risk

The PPA provides valid and reliable measurements that can be used for assessing falls risk and evaluating the effectiveness of interventions.

factor is impaired vision (eg, poor visual acuity and contrast sensitivity), rather than cataracts. Similarly, poor peripheral sensation is likely to be a major risk factor for people with diabetic neuropathy, and muscle weakness is the main risk factor for people with muscle wasting subsequent to bed rest and for people with a history of poliomyelitis. The aim of this article is to outline our approach to falls risk factor assessment (the Physiological Profile Assessment [PPA]) and illustrate the efficacy of this approach through the use of examples.

Conceptual Model

The maintenance of balance depends on the interaction of multiple sensory, motor, and integrative systems.¹ The physiological factors that are the primary contributors to stability are shown in Figure 1. Functioning of each of these factors declines with age,¹⁵ and impairments in each factor are associated with increased risk of falling.¹⁶⁻¹⁹ A marked deficit in any one of these factors may be sufficient to increase the risk of falling; however, a combination of mild or moderate impairments in multiple physiological domains also may increase the risk of falling. By directly assessing an individual's physiological abilities, intervention strategies can be implemented to target areas of deficit.

Rationale for Test Selection

In order for our physiological assessment to be practical in a clinical setting, the individual tests we developed were designed so that they met the following criteria:

1. *Simple to administer.* As with all tests of physical functioning, the PPA needs to be administered in a standardized, rigorous way. However, each test has been designed in an effort to facilitate test administration. Only 1 day of training is required for allied health care personnel (ie, those working in the fields of physical therapy, psychology, exercise science, and nursing, including

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Dr Lord and Dr Menz provided concept/idea and writing. Dr Lord and Ms Tiedemann provided data collection, and all authors provided data analysis. Dr Lord provided project management, fund procurement, and institutional liaisons. Dr Menz and Ms Tiedemann provided consultation (including review of manuscript before submission).

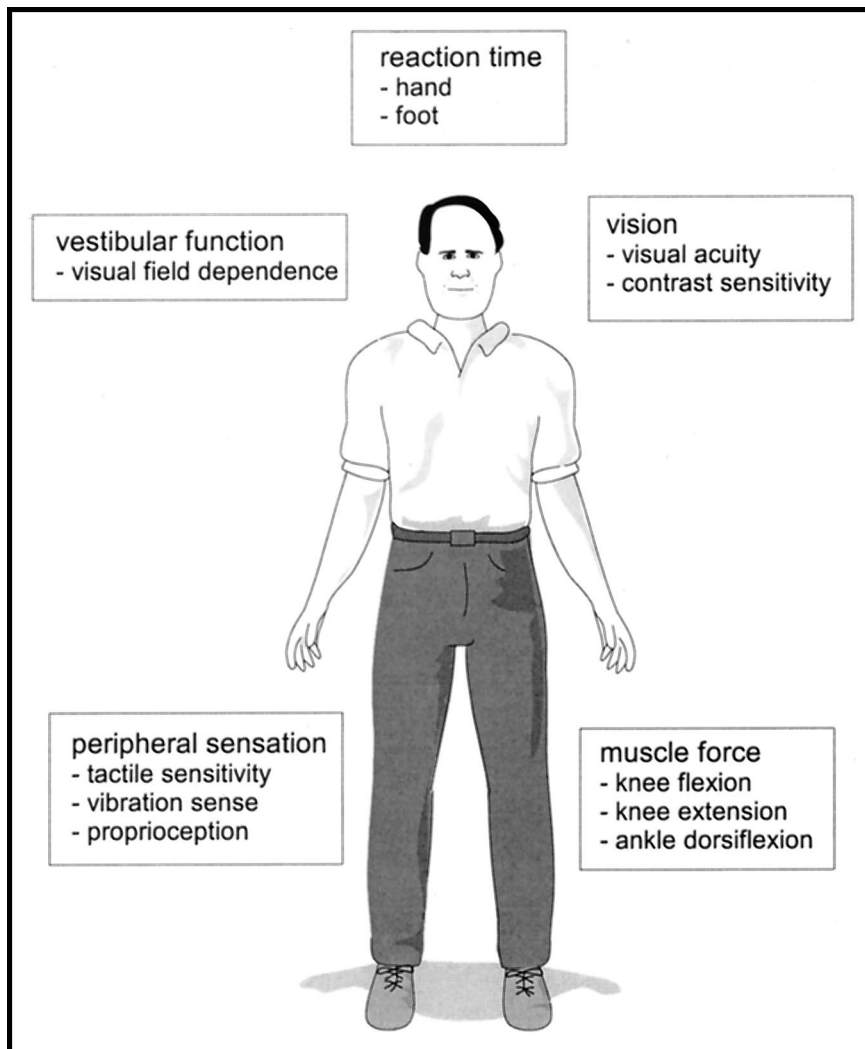


Figure 1. Systems involved in the maintenance of postural stability.¹

physical therapists and nurses' aides) to be proficient in test administration and use of the computer program.

2. *Short administration time.* To test the many domains important in balance control in one session, it is important that each test item take only a few minutes to administer. Quick administration time, we contend, aids participation and avoids fatigue in frail older people.

3. *Feasible for older people to undertake.* The selected tests need to be acceptable to older people, in that they need to be noninvasive and not require excessive effort or cause pain or discomfort. Nonetheless, the tests need to be challenging so as to discriminate between older people with and without sensorimotor and balance impairments. The tests that comprise the PPA have proved to be acceptable to older people and have been used by the Falls and Balance Research Group of the

Prince of Wales Medical Research Institute for over 10 years with more than 4,000 subjects.¹⁵⁻¹⁹

4. *Valid and reliable measurements.* The measurements obtained with the test must have high criterion validity²⁰; that is, they must be able to predict falling in older people. When combined in multivariate discriminant analyses, these measurements have been found to predict those at risk of falling with 75% accuracy in both community and institutional settings.¹⁶⁻¹⁹ The vision, muscle force, reaction time, and balance tests have high test-retest reliability,²¹⁻²³ and although the sensory tests have only moderate test-retest reliability (due to the more exacting nature of the test administration and increased concentration required by the subjects), they yield reliability coefficients consistent with what can be expected in clinical populations (ie, intraclass correlation coefficients [ICCs] in the range of .5 to .7).^{21,24}

5. *"Low-tech" and robust.* If the tests are to be used successfully in large community studies they need to be "low-tech" and robust.

6. *Portability.* A compact, lightweight test apparatus enables testing in a variety of physical settings. Thus, assessment can be done on a temporary or permanent basis in community set-

tings, retirement villages, and health care institutions. Such portability improves participation and adherence, because the clinic can be brought to the target population of often older frail people, rather than relying on them attending a fixed-location laboratory. The equipment for the PPA tests can be easily carried by a single person, and all equipment has been designed to fit into the trunk of a car for easy transport.

7. *Quantitative measurements.* Finally, a fundamental criterion for each test is that they provide continuously scored measurements, that is, quantitative rather than discrete or graded scores. This criterion enables the measurements to be analyzed by parametric statistics, such as analysis of variance, correlation and regression techniques, and discriminant analysis. Because the tests are standardized, we believe this minimizes judgments on part of the test administrator. Quantitative measurements also avoid ceiling and floor effects, which can be

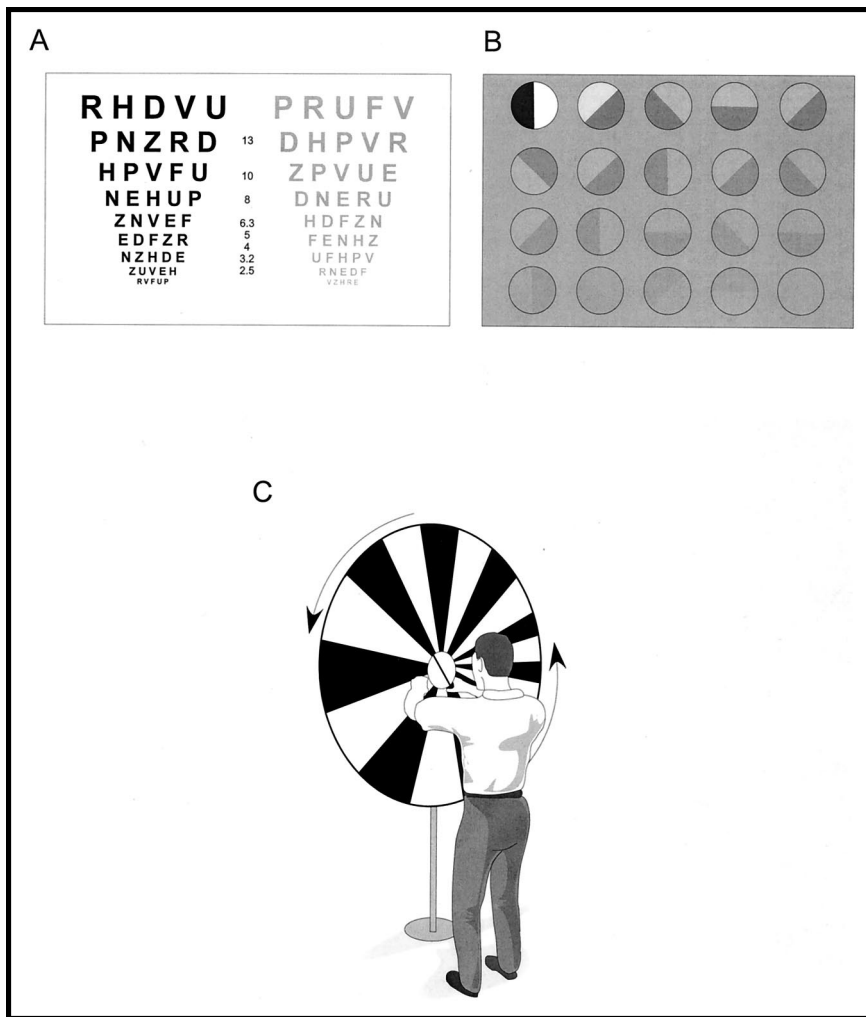


Figure 2. Visual and visual field dependence tests: (A) high- and low-contrast visual acuity, (B) contrast sensitivity, (C) visual field dependence.

quite common in other measures of vision, sensation, muscle force, and balance.

The Physiological Tests

Vision Tests

High- and low-contrast visual acuity. Visual acuity is measured for the PPA by using a letter chart (Fig. 2A) with high- and low-contrast (10%) letters (where contrast = the difference between the maximum and minimum luminance divided by their sum). Acuity is assessed binocularly with subjects wearing their distance glasses (if applicable) at a test distance of 3 m and measured in terms of the minimum angle resolvable (MAR) in minutes of arc. Starting with the high-contrast chart, subjects are asked to read aloud the letters on the chart. The test is scored using a visual acuity conversion

chart (Appendix 1). The score depends on the lowest line on which subjects can read any correct letters and the number of correct letters on that line.²¹

Contrast sensitivity. Edge contrast sensitivity is assessed using the Melbourne Edge Test.²⁵ The chart has 20 circular 25-mm-diameter patches containing edges with reducing contrast with variable orientation as the identifying feature (Fig. 2B). The test uses a 4-alternative forced-choice method of presentation. The edges are presented in the orientations: horizontal, vertical, 45 degrees left, and 45 degrees right. A key card containing the 4 possible edge angles is provided for subject instruction. The lowest contrast patch correctly identified is recorded as the subject's contrast sensitivity in decibel units, where 1 dB = $10 \log_{10}$ contrast.

Vestibular Function Tests

Visual field dependence. The visual field dependence test²⁶ places vision in conflict with vestibular and other postural senses and provides an indirect measurement of vestibular functioning. In this test, subjects attempt to align a straight edge to the true vertical while exposed to a rotating visual stimulus that extends over most of the visual field (Fig. 2C).

Errors in aligning the rod to the true vertical are measured in degrees.

Our group^{16,18} has used 2 other screening tests of vestibular function: Fukuda's vestibular x-writing and stepping tests.^{27,28} However, we found that poor test performances were not related to either poor balance²¹ or falls¹⁸ and that measurements obtained with these tests had low to moderate test-retest reliability (ICCs [3,1] of .16 for the x-writing test and .51 for the stepping test). Therefore, we have removed these tests from the screening battery. We are currently developing what we hope will be more precise screening tests of vestibular functioning for subsequent versions of the PPA.

Peripheral Sensation Tests

Tactile sensitivity. Tactile sensitivity is measured with a Semmes-Weinstein-type pressure aesthesiometer.²⁹ This

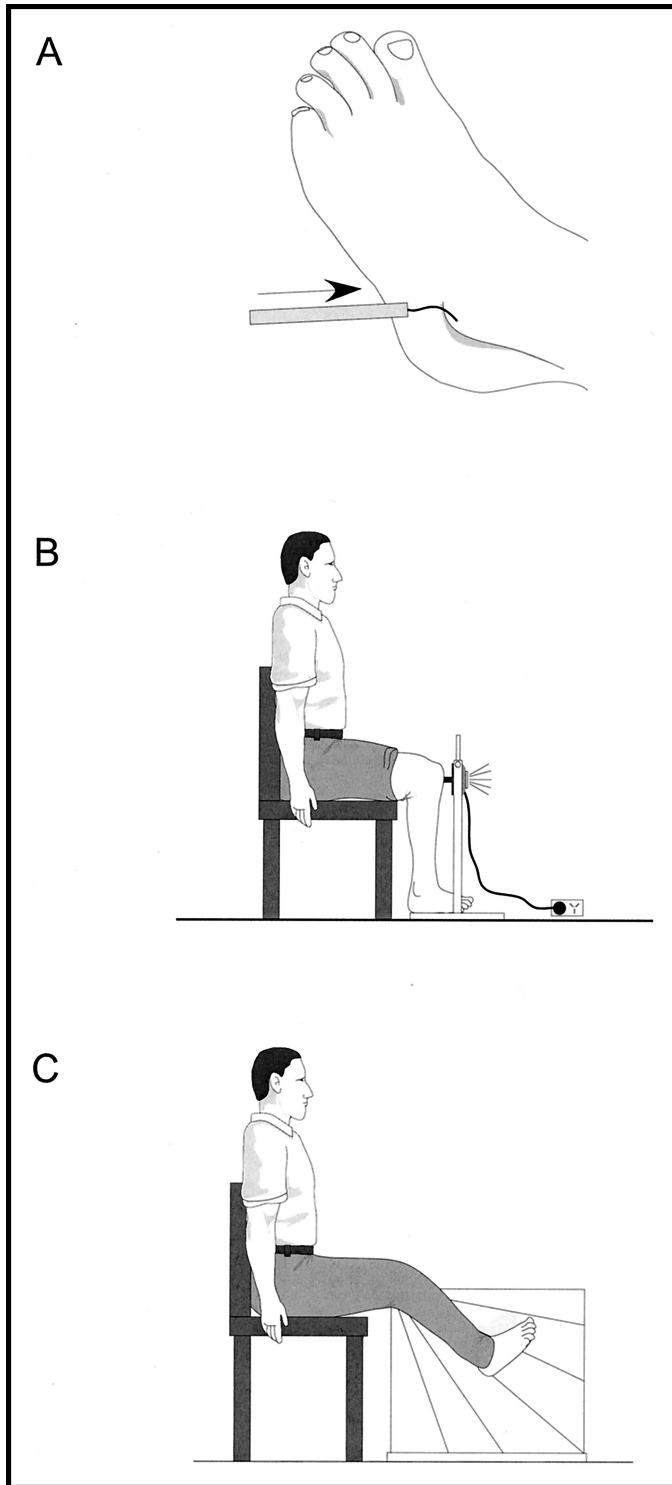


Figure 3. Peripheral sensation tests: (A) tactile sensitivity, (B) vibration sense, (C) proprioception.

instrument contains 8 nylon filaments of equal length, but varying in diameter. The force (in grams) required to bend each filament is precalibrated and ranges from 0.0045 g to 447 g. The filaments are applied to the center of the lateral malleolus of the ankle (Fig. 3A). Subjects are instructed that the filament will be placed

on their ankle when the examiner says “A” or “B,” and if they feel the filament in contact with the skin, they must report to the examiner whether they felt it on “A” or “B.” Tactile threshold is determined using a staircase technique, which involves presenting suprathreshold filaments initially, then applying smaller and smaller filaments until the subject can no longer detect them. The examiner then applies larger filaments until a filament is detected. The touch threshold is determined from a minimum of 3 ascending and descending steps. The pressure (in grams) exerted by this filament is converted to $\log_{10} 0.1$ mg, yielding a scale of approximately equal-intensity intervals between filaments.

Vibration sense. Vibration sense is measured using an electronic device* that generates a 200-Hz vibration of varying intensity. The vibration is applied to the tibial tuberosity via a 1-cm-diameter rubber stopper and is measured in microns of motion perpendicular to the body surface (Fig. 3B). Three readings in the ascending mode and 3 readings in the descending mode are made, and an average of these 6 measurements is recorded as the vibration threshold.²¹

Proprioception (position sense). *Proprioception* has been defined as the discrimination of the positions and movements of body parts based on information other than visual, auditory, or verbal.³⁰ Proprioception is assessed for the PPA using an established and validated lower-limb matching task.³¹ In this test, subjects are seated with their eyes closed and are asked to align their lower limbs simultaneously on either side of a vertical clear acrylic sheet (60×60×1 cm) inscribed with a protractor and placed between their legs (Fig. 3C). To prevent limited motion at the knee joint from confounding the results of this test, the examiner needs to ensure that subjects match their limbs near the midrange of knee joint motion.³¹ Each trial is undertaken relatively quickly, with rests between trials, to avoid weakness unduly influencing the results. Any difference in aligning the lower limbs (indicated by disparities in matching the great toes on either side of the acrylic sheet) is measured in degrees. After 2 practice trials, an average of 5 experimental trials is recorded.

We have previously found that lower-extremity muscle force is weakly correlated with performance on this test, suggesting that it is not a major confounding factor (Lord SR, unpublished observations, 2001). Similarly, because the test is performed quickly and subjects are allowed to rest between trials, muscular endurance is unlikely to influence the results.

* Balance Systems, PO Box 915, Caringbah, Sydney, New South Wales, 1495, Australia.

Muscle Force Tests

Force production of 3 lower-extremity muscle groups (knee flexors and extensors and ankle dorsiflexors) are measured for the PPA because these muscle groups are important when performing daily tasks such as rising from a chair³² and walking.¹³ Whipple et al³³ and Studenski et al³⁴ have compared the force production of these muscle groups (as well as that of the ankle plantar flexors) in residents of nursing homes with and without a history of falls (“fallers” and “nonfallers”). Both studies demonstrated that fallers were weaker than nonfallers in each muscle group, with ankle muscle weakness particularly evident in the fallers.

Maximal isometric muscle force for the PPA is measured following the experimental protocol described by Gandevia³⁵ (Fig. 4). Testing of the knee extensor and flexor muscles is performed using a spring gauge attached to the subject’s leg using a webbing strap with a Velcro fastener.[†] The force of the knee extensor and flexor muscles is measured with the subject sitting in a tall chair with a strap around the leg 10 cm above the ankle joint, and the hip and knee joint angles positioned at 90 degrees. In 3 trials per muscle group, the subject attempts to pull against the strap assembly with maximal force for 2 to 3 seconds, and the greatest force for each muscle group is recorded. The testing of ankle dorsiflexion force is done using a footplate attached to a spring gauge. While the subject is sitting in a tall chair, the foot is secured to the footplate using a webbing strap with a Velcro fastener with the angle of the knee at 110 degrees. In 3 trials, the subject attempts maximal dorsiflexion of the ankle, and the greatest force (in kilograms) is recorded.^{21,35}

For the knee extension test, the spring gauge is affixed to a crossbar position behind the subject. For the knee flexion test, the spring gauge is affixed to a crossbar positioned in front the subject. For the ankle dorsiflexion test, the spring gauge is fixed to the bottom of a footplate. The subject’s own weight stabilizes the rig for the knee extension test and for all except the strongest subjects in the knee flexion test. For testing of knee flexion force in stronger subjects, the chair can be affixed to the floor or a baseplate. The footplate for the assessment of ankle dorsiflexion force is designed so that it can be stabilized by the test administrator placing a foot on its baseplate.

Although we believe it is a desirable measure, ankle plantar-flexion force is not included in the PPA because it is difficult to assess with screening equipment, in that equipment is required to stabilize the knee. However, ankle dorsiflexion force may provide an adequate mea-

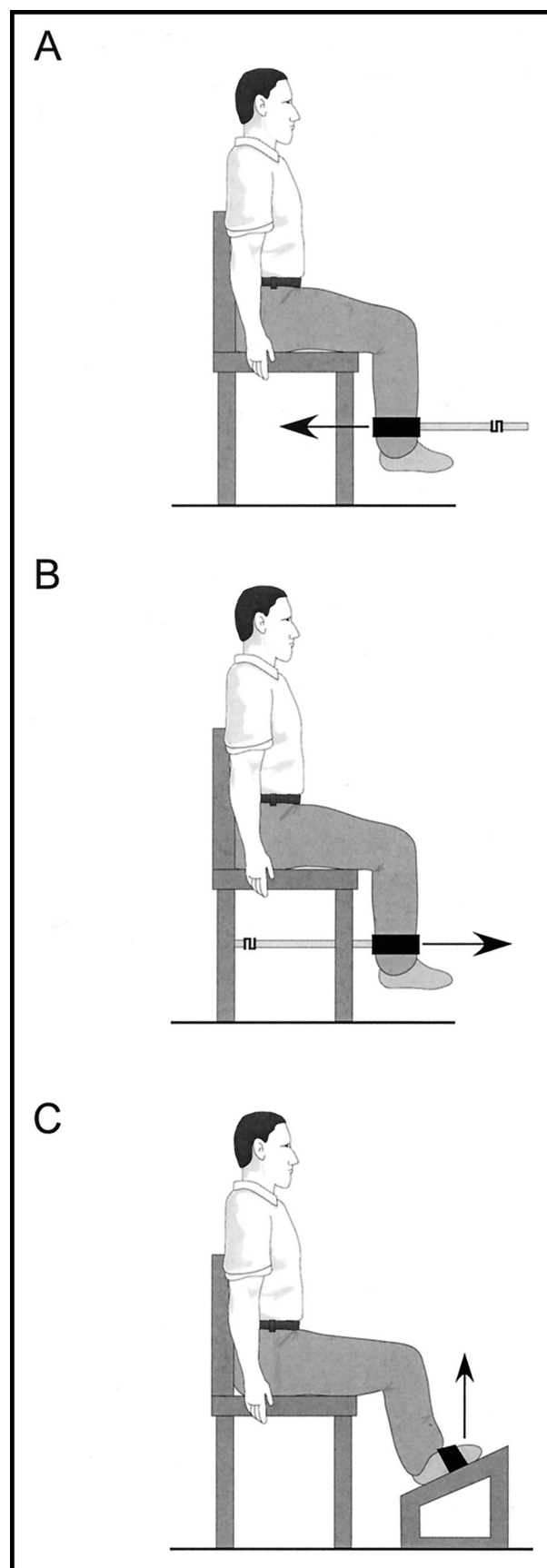


Figure 4. Muscle force tests: (A) knee flexion, (B) knee extension, (C) ankle dorsiflexion.

[†] Velcro USA Inc, 406 Brown Ave, Manchester, NH 03103.

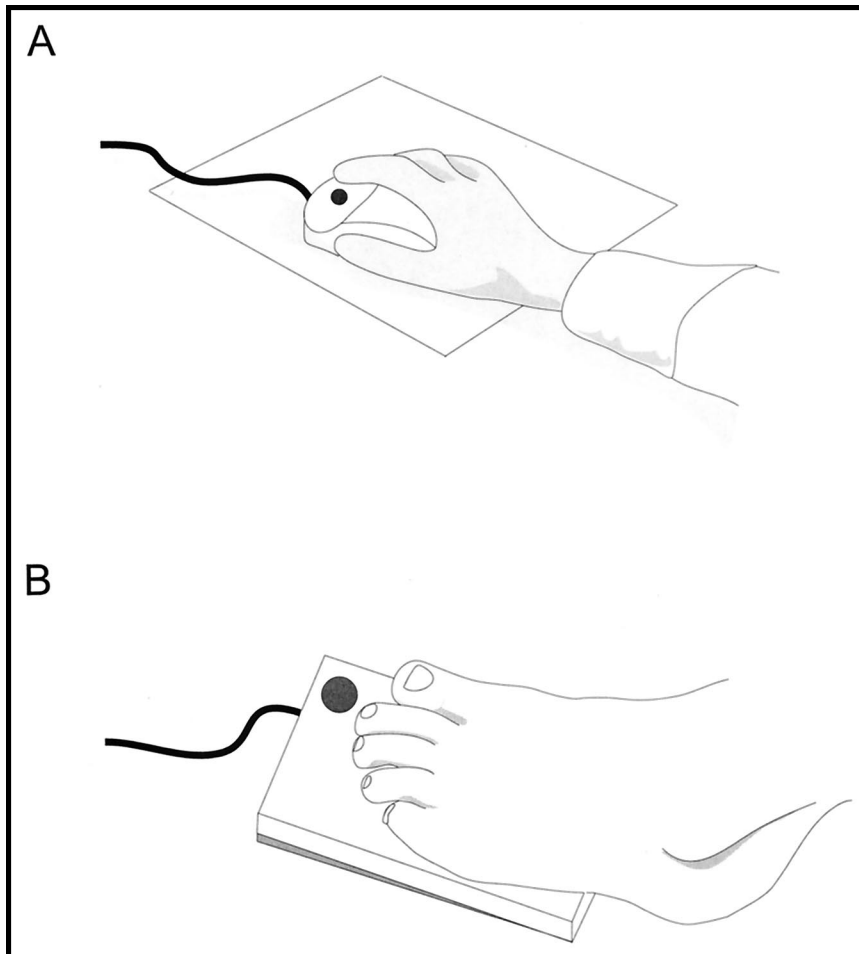


Figure 5. Reaction time tests: (A) hand, (B) foot.

sure of ankle muscle force, as a study by our group has shown that ankle dorsiflexion force and ankle plantarflexion force (when assessed using a rig that stabilizes the leg) are highly correlated ($r=.81$, $P<.001$) in a group of 45 young and elderly subjects (Lord SR, unpublished observations, 2002). Sherrington³⁶ also found that muscle force measurements obtained using a spring gauge were strongly correlated with measurements obtained using a strain gauge, a sphygmomanometer, and a hand-held dynamometer.

Reaction Time Tests

Reaction time for the PPA is assessed in milliseconds using a hand-held electronic timer* and a light as the stimulus and depression of a switch by the finger and the foot as the responses.²¹ The light stimulus is located adjacent to the response switches and is bright (ie, supra-threshold) to ensure that the tests are not influenced by the subject's visual acuity. The timer has a built-in variable delay of 1 to 5 seconds to remove any cues that could be gained from the test administrator commencing each trial by pressing the "start" button. A

modified computer mouse is used as the response box for the finger press task, and a pedal switch is used for the foot press task (Figs. 5A and 5B). Five practice trials are undertaken, followed by 10 experimental trials.

Balance Tests

Postural sway is measured using a sway meter that measures displacements of the body at waist level. The device consists of a 40-cm-long rod with a vertically mounted pen at its end. The rod is attached to the subject by a firm belt and extends posteriorly. As the subject attempts to stand as still as possible for 30 seconds, the pen records the subject's sway on a sheet of millimeter graph paper fastened to the top of an adjustable-height table (Figs. 6A and 6B). Testing is performed, with eyes open and closed, on a firm surface and on a medium-density foam rubber mat (15 cm thick). One trial of each condition is performed in the order of the difficulty of the test: on floor with eyes open, on floor with eyes closed, on foam rubber mat with eyes open, and on foam rubber mat with eyes closed. Total sway (number of square millimeter squares traversed by the pen) and anteroposterior and mediolateral sway are recorded for the 4 tests.²¹ Sherrington³⁶ also found that sway measure-

ments obtained with the sway meter are strongly associated with center-of-pressure sway measurements obtained from a forceplate, indicating that this simple technique provides similar information about standing balance.

Validity of PPA Measurements

A series of large-scale studies have been performed to evaluate the ability of the PPA tests to discriminate between elderly fallers and nonfallers. In each of these studies, a *fall* was defined as "an event that results in a person coming to rest unintentionally on the ground or lower level, not as the result of a major intrinsic event (such as a stroke) or overwhelming hazard." In a 1-year prospective study of 95 residents of an intermediate care hostel, aged 59 to 97 years, the PPA measurements were used to correctly classify subjects into a multiple falls group (2 or more falls) or a non-multiple falls group (no falls or 1 fall) with an accuracy of 79%.¹⁸ This categorization of falls status was used because it has frequently been found that multiple falls within a year are more likely to indicate physiological impairments and chronic conditions than does a single fall.^{1,37,38} In a

second 1-year prospective study, this time involving 414 community-dwelling women aged 65 to 99 years, the PPA measurements could be used to correctly classify subjects into a multiple falls group or a non-multiple falls group with an accuracy of 75%.¹⁶ The largest-scale study using the PPA was a cross-sectional investigation of 1,762 community-dwelling people aged 60 to 100 years. Subjects with a history of falls exhibited reduced knee extension force, poorer tactile sensitivity, greater visual field dependence, and greater sway (independently of age) than those without a history of falls.¹⁹

Reliability of PPA Measurements

Test-retest reliability of measurements obtained with the PPA has been determined in several studies with varying intertest periods.^{19,21,22} Table 1 presents data from 2 studies that involved administration of the tests to community-dwelling older people on 2 occasions, 2 weeks apart. The sample for the vision, sensation, muscle force, and reaction time tests comprised 31 people (13 men, 18 women) aged 76 to 87 years ($\bar{X}=80.8$, $SD=3.1$) (Lord SR, unpublished data, 2002). These subjects took part in other research studies conducted by the Falls and Balance Research Group of the Prince of Wales Medical Research Institute.³² The prevalence of self-reported major medical conditions and limitations in activities of daily living in these subjects was similar to that of the larger sample from which it was drawn. Eight subjects (25.8%) reported having heart disease, 3 (9.7%) reported having a stroke, 11 (35.5%) reported having high blood pressure, 12 (38.7%) reported having osteoarthritis, and 2 (6.5%) reported having diabetes. The sample for the sway tests comprised 34 people (13 men, 21 women) aged 50 to 70 years ($\bar{X}=62.4$, $SD=6.3$).²² In this sample, 4 subjects (11.8%) reported having a history of heart attack or stroke, 11 (32.4%) reported having high blood pressure, 17

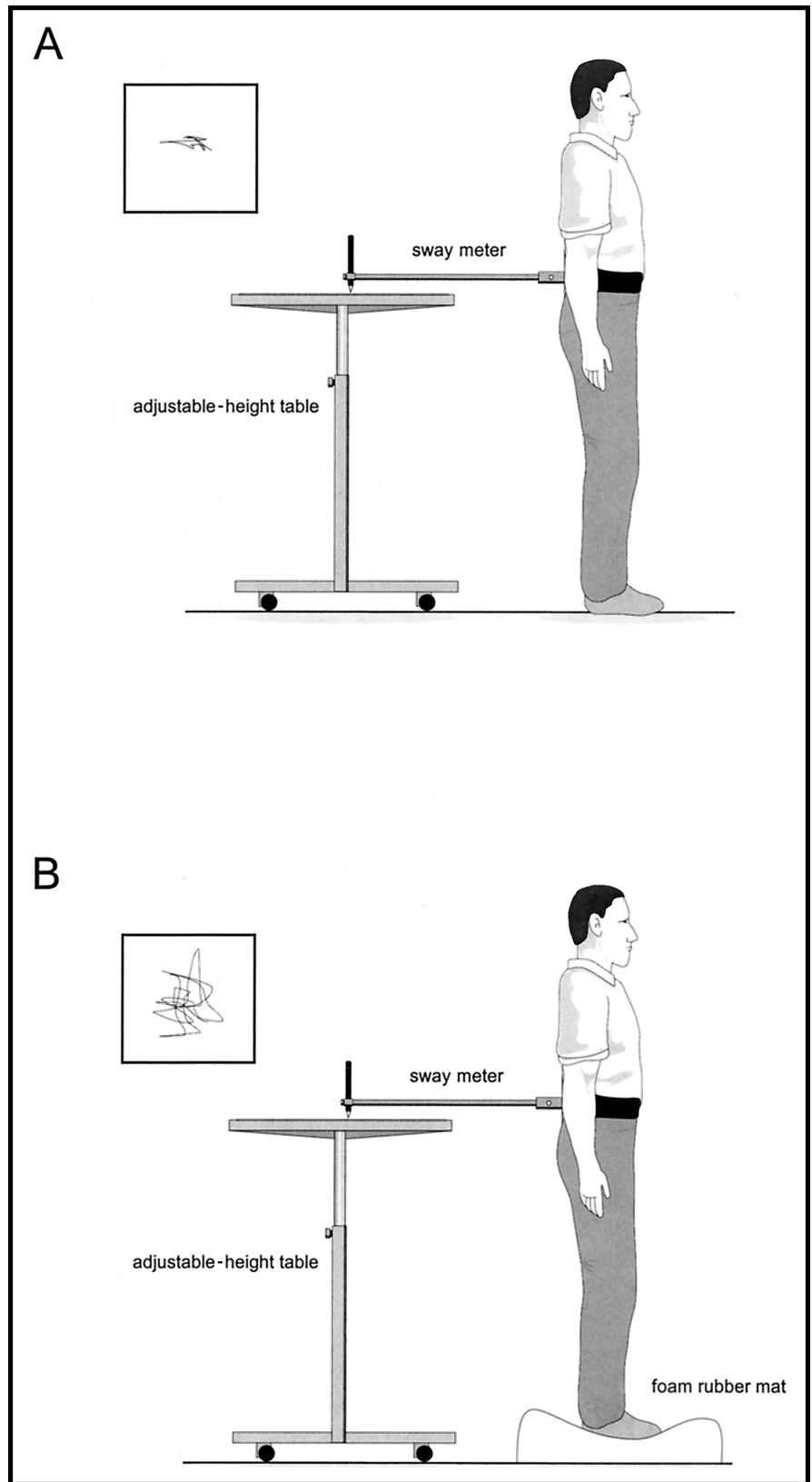


Figure 6. Postural sway tests: (A) standing on the floor, (B) standing on a foam rubber mat.

Table 1.
Test-Retest Reliability Data for the Physiological Profile Assessment Measures^a

| Measure | ICC (95% CI) |
|--|---------------|
| Visual acuity–high contrast ^b | .82 (.66–.91) |
| Visual acuity–low contrast ^b | .81 (.64–.90) |
| Contrast sensitivity ^b | .81 (.70–.88) |
| Visual field dependence ^b | .71 (.46–.86) |
| Tactile sensitivity ^b | .51 (.19–.74) |
| Vibration sense ^b | .78 (.59–.89) |
| Proprioception ^b | .50 (.15–.74) |
| Knee flexion force ^b | .88 (.77–.94) |
| Knee extension force ^b | .97 (.93–.98) |
| Ankle dorsiflexion force ^b | .88 (.76–.94) |
| Reaction time–hand ^b | .69 (.45–.84) |
| Reaction time–foot ^b | .78 (.59–.89) |
| Sway on floor–eyes open ^c | .68 (.45–.82) |
| Sway on floor–eyes closed ^c | .85 (.72–.92) |
| Sway on foam rubber mat–eyes open ^c | .57 (.30–.76) |
| Sway on foam rubber mat–eyes closed ^c | .83 (.69–.91) |

^a ICC=intraclass correlation coefficient (2,1), CI=confidence interval.

^b Unpublished data from 31 people (13 men, 18 women) aged 76 to 87 years (\bar{X} =80.8, SD=3.1).

^c Data from 34 people (13 men, 21 women) aged 50 to 70 years (\bar{X} =62.4, SD=6.3).²²

(50.0%) reported having osteoarthritis, and 2 (5.9%) reported having diabetes. Many subjects in both samples had multiple conditions.

In a third study, interrater reliability was determined for the 2 sensation tests that demonstrated only moderate test-retest reliability: tactile sensitivity and proprioception (Lord SR, unpublished data, 2002). In this study, 2 examiners independently conducted the tests with 10 of the subjects who took part in the test-retest reliability study. The ICC for the tactile sensitivity test was .81 (95% confidence interval [CI]=.40–.95), and the ICC for the proprioception test was .70 (95% CI=.17–.92).

Application of the PPA

The PPA has 2 versions: a comprehensive (or long) version and a screening (or short) version. The 2 versions provide the same overall falls risk score. However, the comprehensive version provides information on a broad array of physiological measures that provide insight into each subject's impairments, including measurements of force in multiple lower-extremity muscle groups. Thus, we believe the comprehensive version is suitable for clinical settings (rehabilitation, physical therapy, and occupational therapy clinics and departments and dedicated falls clinics) that can dedicate 45 minutes per person for a falls risk assessment. The screening version takes 10 to 15 minutes to administer and is more suitable for settings in which time constraints are an issue (ie, acute care hospitals and where the PPA forms only part of a general health screening). The screening version contains 5 of these items: a test of vision (edge

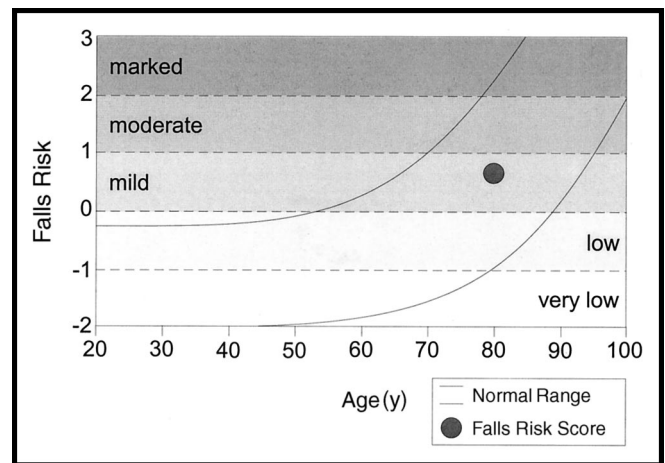


Figure 7. Falls risk graph for a 79-year-old woman. Normal ranged based on data for a randomly selected sample of 550 community-dwelling women aged 20 to 99 years.¹⁵

contrast sensitivity), peripheral sensation (proprioception), lower-extremity force (knee extension force), reaction time using a finger press as the response, and body sway (sway when standing on the medium-density foam rubber mat). We identified these 5 items from discriminant function analyses as being the most important for discriminating between fallers and nonfallers in both institutional and community settings.^{16,18,19}

For both the short and long forms, a Web-based computer software program[†] has been developed to assess an individual's performance in relation to a normative database compiled from the large-scale studies.^{16,18,19} This program produces a falls risk assessment report for each individual that includes the following 4 components:

1. A graph indicating an individual's overall falls risk score.
2. A profile of the individual's test performances. This profile allows a quick identification of physiological strengths and weaknesses.
3. A table indicating the individual's test performances in relation to age-matched norms.
4. A written report that explains the results and makes recommendations for improving functional performances or compensating for any impairments identified.

Figures 7 and 8 and Table 2 present the output of the comprehensive version of the PPA for a 79-year-old woman.

[†] www.powmri.unsw.edu.au/FBRG/calculator.htm.

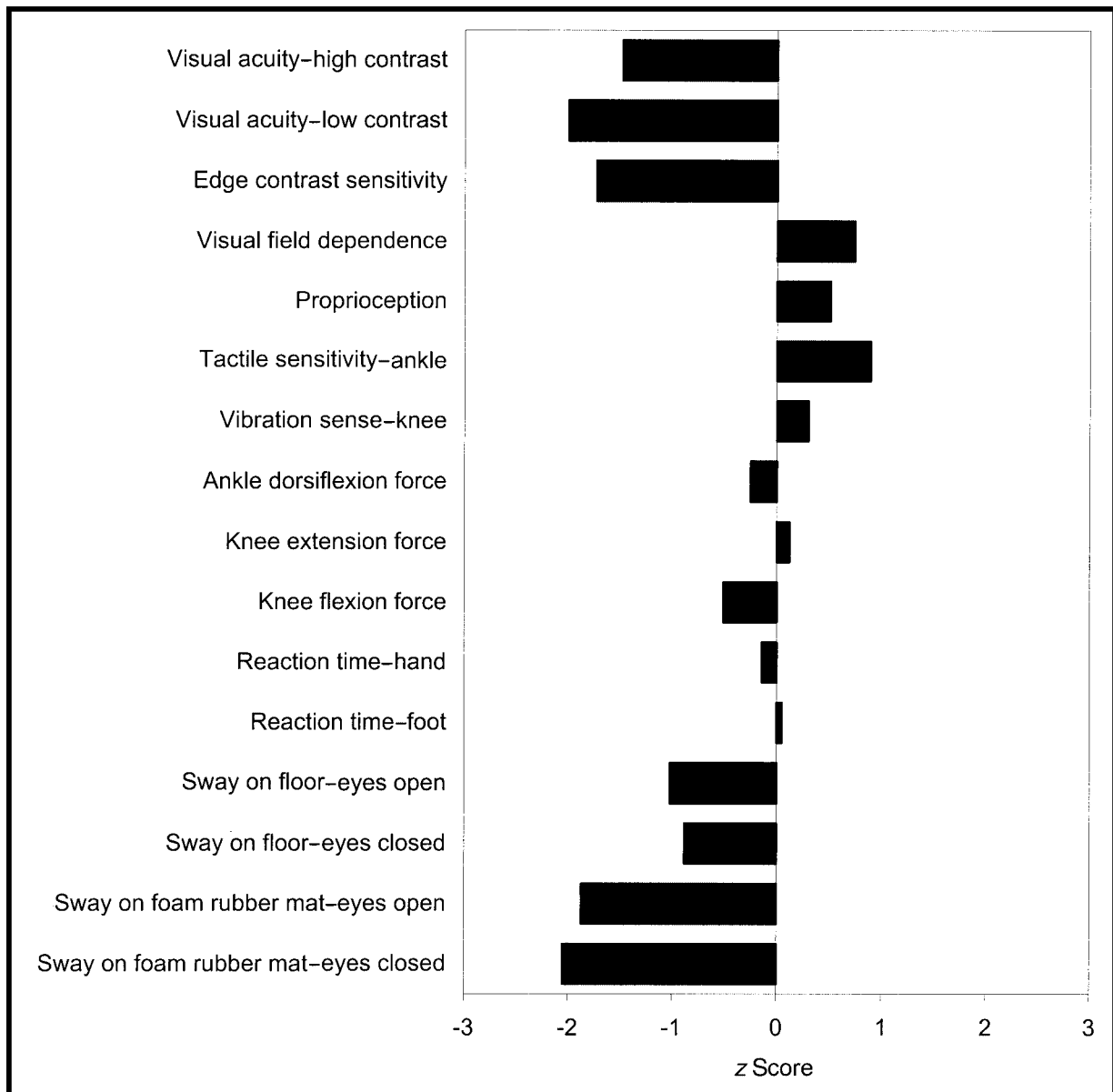


Figure 8. Comprehensive Physiological Profile Assessment (PPA) z-score output for a 79-year-old woman.

Figure 7 shows her falls risk score—a single index score derived from discriminant function analysis using the data from large-scale studies.^{16,18,19} The discriminant function is made up of weighted scores of independent risk factors (ie, visual contrast sensitivity, lower-extremity proprioception, knee extension force, reaction time, and sway on the compliant [foam rubber] surface). The graph presents the falls risk score in relation to people of the same age and falls risk criteria ranging from very low to marked.

Figure 8 shows the subject's test performance profile graph. This graph presents the test results in standardized (z) scores form, using the reference data from the large-scale studies.^{16,18,19} Thus, a score of zero indicates average performance for people aged 65 years and over,

positive scores indicate above-average performances, and negative scores indicate below-average performances. Each unit represents one standard deviation. Because the scores have been standardized, the test results can be compared with each other.

Table 2 shows the subject's raw test scores presented in a conventional manner that complement the test performance profile graph. For each individual, reference ranges for each test are provided for (1) sex-matched young subjects without known pathology or impairments and (2) age- and sex-matched subjects.^{15,19}

Finally, the computer program compiles a written report for each subject. An example is presented in Appendix

Table 2.

Individual Test Performance for a 79-Year-Old Woman in Relation to Reference Ranges for Sex-Matched Young Subjects Without Known Pathology or Impairments (Group 1) and Age- and Sex-Matched Subjects (Group 2)¹⁵

| Test | Score | Group 1 | Group 2 ^a |
|-------------------------------------|------------------|-----------|----------------------|
| Vision | | | |
| Visual acuity–high contrast | 2.5 ^b | 0.54–0.82 | 0.83–1.58 |
| Visual acuity–low contrast | 6 ^b | 0.76–1.05 | 1.32–2.65 |
| Edge contrast sensitivity | 13 ^b | 23–24 | 20–24 |
| Visual field dependence | 1.5 | 0.0–2.0 | 0.5–6.5 |
| Sensation | | | |
| Tactile sensitivity–ankle | 3.7 | 3.22–4.08 | 3.61–4.31 |
| Vibration sense–knee | 15.5 | 2–5 | 7–34 |
| Proprioception | 1 | 0.2–1.4 | 0.4–2.4 |
| Muscle force | | | |
| Ankle dorsiflexion | 7 | 10–15 | 6–10.5 |
| Knee extension | 21 | 35–58 | 15–29 |
| Knee flexion | 10 | 22–29 | 7–34 |
| Reaction time | | | |
| Hand | 251 | 182–236 | 197–267 |
| Foot | 278 | 213–273 | 230–305 |
| Balance | | | |
| Sway on floor–eyes open | 120 ^b | 35–70 | 40–100 |
| Sway on floor–eyes closed | 158 | 55–95 | 50–160 |
| Sway on foam rubber mat–eyes open | 286 ^b | 60–110 | 65–163 |
| Sway on foam rubber mat–eyes closed | 581 ^b | 70–185 | 108–285 |

^aWomen aged 75 to 79 years.

^bWorse than average age-matched.

2. It summarizes the findings, highlights below-average performances, and makes individual recommendations for reducing the risk for falls.

Examples of the PPA in Clinical Groups

The Falls and Balance Research Group of the Prince of Wales Medical Research Institute have used the PPA for numerous groups who have an increased risk of falling, including people aged 65 years and over,^{16–19} people with diabetes mellitus,³⁹ and people with a history of poliomyelitis.⁴⁰ Figure 9 shows typical examples of the z-score output for a young person without known pathology or impairments (27 years of age), a person with age-related macular degeneration (82 years of age), a person with diabetes mellitus (67 years of age), and a person with a history of poliomyelitis (51 years of age). As shown in the graphs for subjects with diagnosed diseases, their performance reflects the known manifestations of their diseases.

As expected, the older person with macular degeneration performed poorly in each of the visual tests. She also demonstrated impaired balance, particularly in the postural sway test with eyes open on the foam rubber mat. Our research group has previously found that although vision is not critical for the maintenance of stability when standing on a firm surface, standing on a compliant surface relies more strongly on visual input because

proprioceptive input from the feet and ankles is reduced.^{15,21,41} In this situation, visual acuity and stereopsis play an important role in stabilizing balance.⁴¹ This finding indicates that people with macular degeneration are at risk for falling, not only because of a reduced ability to perceive hazards in the environment but also because of impaired balance. Older people with this condition are likely to be at particular risk when standing or walking in challenging environmental conditions such as on uneven or compliant surfaces.

The older person with diabetes mellitus scored poorly on tests of peripheral sensation, which reflects the presence of diabetic peripheral neuropathy. This finding is consistent with the results from a previous study conducted by our group³⁹ comparing 25 people with diabetes mellitus with 40 age-matched control subjects. Despite exhibiting above-average lower-extremity muscle force, this subject also performed poorly on the postural sway tests, most notably (in relative terms) in the unchallenged standing on floor conditions. This finding

is consistent with research that has shown that peripheral sensation is the most important contributor to postural stability in quiet standing^{15,21} and provides insight into why patients with diabetes have an increased risk for falls.^{42,43}

The older person with a history of poliomyelitis performed poorly on the tests of lower-extremity force, proprioception, and postural sway on a foam rubber mat, but exhibited above-average vision and average tactile sensation and vibration sense. A recently completed study of 40 people with a history of poliomyelitis (28–71 years of age) and 38 age-matched control subjects confirmed that people with a history of poliomyelitis represent a clinical group with lower-limb weakness, but in whom most other physiological factors associated with balance are similar to those in the general community.⁴⁰ Consistent with previous studies of older people,^{15,21,41} reduced muscle force impairs standing balance when subjects stand on a compliant surface. This subject's reduced proprioceptive score is also of interest as recent research that has shown that muscle spindles (which provide an important contribution to proprioceptive acuity⁴⁴) are much less effective in signaling movement when contraction levels are high.⁴⁵ This suggests that muscle weakness results in a relative failure of proprioceptive input from the legs, and with such

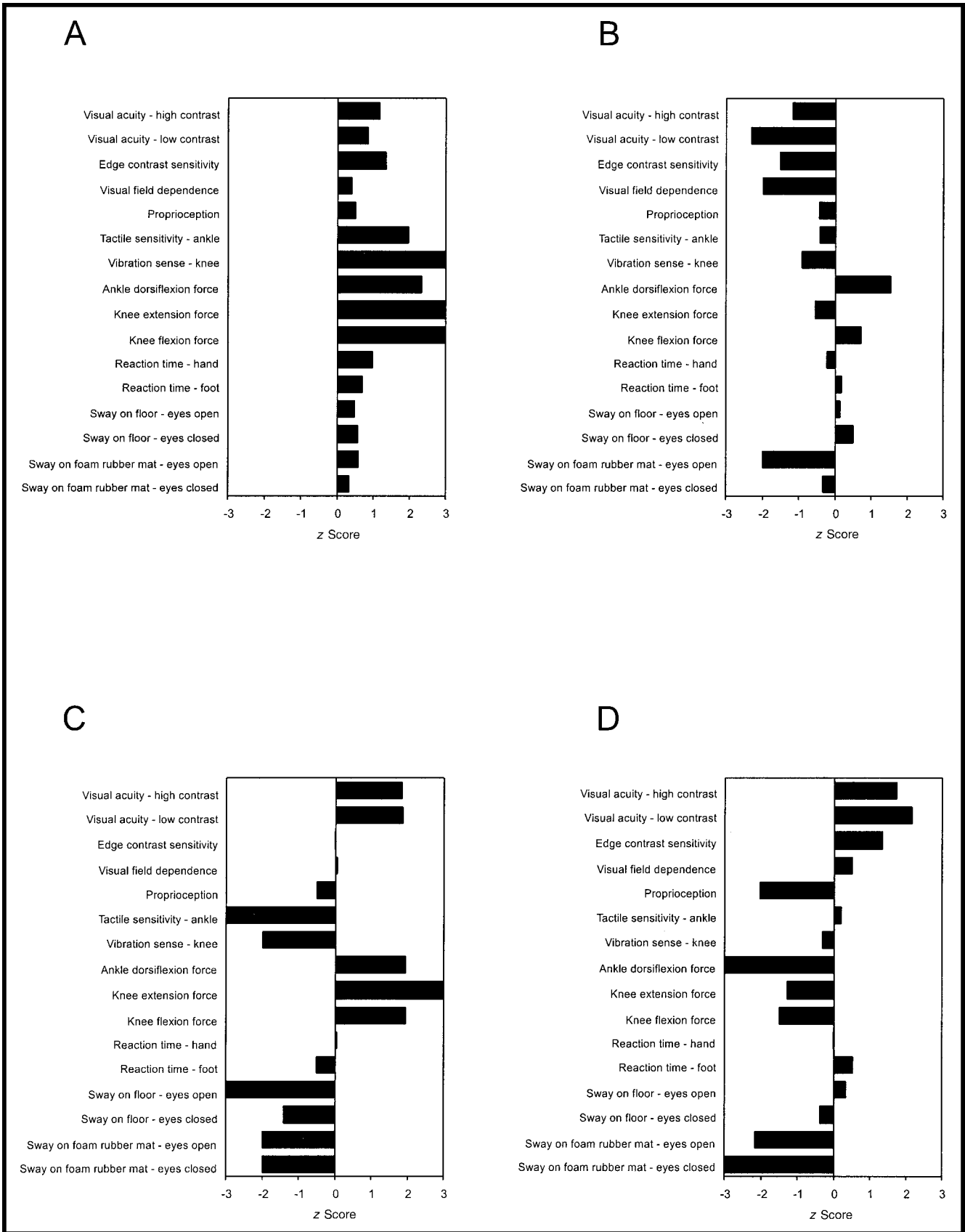


Figure 9. Physiological Profile Assessment z-score outputs for various groups: (A) young adult (27 years of age), falls risk score=-0.87; (B) older person with macular degeneration (82 years of age), falls risk score=1.55; (C) person with diabetic peripheral neuropathy (67 years of ages), falls risk score=1.55; (D) older person with a history of poliomyelitis, (51 years of age) falls risk score=1.75.

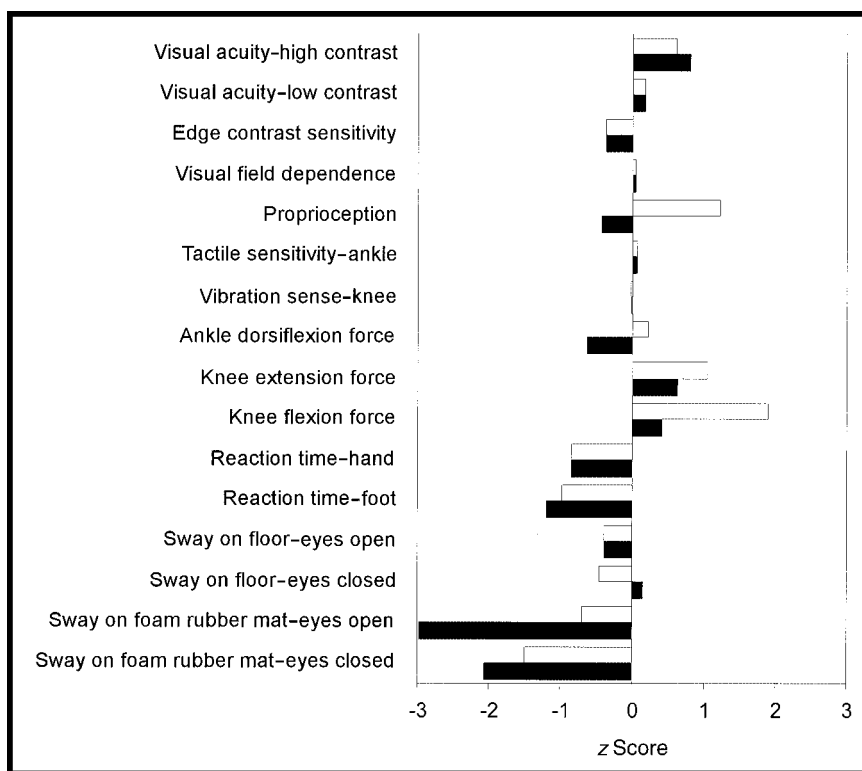


Figure 10. Physiological Profile Assessment z-score output for a 79-year-old woman before and after 12-month exercise intervention. Initial scores are shown in black, and retest scores are shown in white. Improvements are evident for proprioception, lower-extremity muscle force, and postural sway following the intervention.

reduced motor output, the availability of other sensory inputs becomes increasingly important for maintaining stability.

Use of the PPA in Clinical Trials

We believe the individual muscle force, speed, and balance tests are not just important for assessing falls risk but also can be useful outcome measures in exercise studies.^{22,46} The Falls and Balance Research Group of the Prince of Wales Medical Research Institute is currently conducting a randomized controlled trial involving 600 community-dwelling people aged 75 years and over. The major aim of the study is to determine whether tailored interventions identified by the comprehensive PPA can reduce the rate of falling by maximizing performance in muscle force, balance, vision, peripheral sensation, and visual field dependence.

Examples of the use of the PPA in the above randomized controlled trial are shown in Figures 10 and 11. Figure 10 shows the PPA z-score profile for a 79-year-old woman before her tailored intervention. At the initial assessment, she exhibited deficits in foot press reaction time and postural sway when standing on the foam rubber mat. Subsequently, she was enrolled in 12-month exer-

cise program, comprising 1-hour group exercise classes conducted twice a week. Trained exercise instructors led the classes, and exercises were directed towards the areas of weakness identified by the PPA. The exercises within the individual programs included seated and standing strengthening exercises for ankle plantar flexors, knee extensors, and knee flexors using ankle cuffs with 0.5-kg pole weights. Training to increase muscle force included sit-to-stand practice using weight belts, step-ups, and stair climbing. Balance training consisted of tandem walking, walking over uneven surfaces and around obstacles, and stability exercises that involved controlled leaning balance.²³ Reaction time exercises involved participants reaching or stepping forward, sideways, and backward to touch colored foam circles affixed to a board.

Following the exercise program, improvements were found in proprioception, muscle force in all 3 lower-extremity muscle groups, and postural sway on the foam rubber mat. Figure 11 shows the falls risk graph of the trial participant after the intervention. Her

initial falls risk score was 2.7, indicating a marked risk of falling, but following the intervention, her score was reduced to 0.93, indicating a mild risk of falling. This example suggests that the exercise program may have reduced falls risk, primarily through improvement in muscle force and an associated improvement in standing balance. Interestingly, it is also possible that improvements in muscle force may bring about improvements in proprioception, because it has been found that the precision with which humans can detect movements of the body based on proprioception is related to the level of muscle contraction or overload.⁴⁶

Strengths and Limitations of the PPA

We designed the PPA to focus on physiological risk factors (impairments), and this approach has been found to be useful in predicting falls in older people in prospective studies. We acknowledge, however, that there are other risk factors not included in our model, including psychological factors (eg, dementia; depression; cognitive ability, including the ability to divide attention and successfully perform dual tasks⁴⁷⁻⁴⁹), adverse effects of psychoactive medications,⁶ and all aspects of medical conditions such as Parkinson disease,¹² stroke,¹¹ lower-limb amputation,⁵⁰ postural hypotension,⁵¹ and ves-

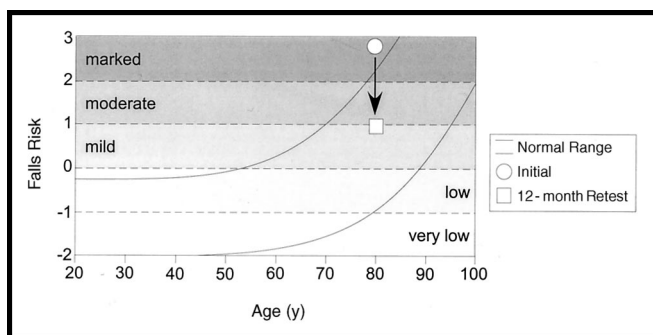


Figure 11. Falls risk graph of a 79-year-old woman before and after 12-month exercise intervention. The initial falls risk score was 2.7, and the retest falls risk score was 0.93. Normal range based on data for a randomly selected sample of 550 community-dwelling women aged 20 to 99 years

tibular disease.⁵² Therefore, we believe the PPA needs to be viewed as being complementary to the traditional medical approach based on diagnosis of diseases.

We also acknowledge that as the PPA requires specialized equipment and the data require computer processing and that it has cost and time disadvantages over other simple assessment measures not requiring equipment or computer analysis. These disadvantages, in our view, should be balanced with the advantages that the PPA provides in terms of providing a validated assessment of the risk of falling and physiological functioning across multiple domains.

We have found, like other researchers,²⁴ that the measurements obtained with the sensory tests are less reliable than those obtained with the motor tests. We believe, however, that there is acceptable interrater reliability (ie, .70 for proprioception and .81 for tactile sensitivity), and this suggests that the moderate test-retest reliability relates mostly to variable subject performance and not experimenter measurement error. Despite this, each of the sensation measures appears to be useful in discriminating significantly between older fallers and non-fallers. Thus, it appears that the tests are useful in this regard because their variability within subjects is lower than their variability between falls outcome groups. Finally, we acknowledge that to refine and enhance the PPA, validated assessments of depth perception, vestibular function, and leaning balance are desirable.

Conclusions

Gillespie et al,⁵³ in a recent systematic review of interventions used to prevent falls in older people, concluded that protection against falling may be maximized by interventions that target multiple risk factors in individual patients and that health care providers should consider screening of older people who are at risk for falls, followed by targeted interventions for deficit areas. We feel that the PPA fulfills these criteria by utilizing vali-

dated assessments and normative data from large-scale studies to identify key physiological risk factors (impairments) that can be targeted with interventions.

The PPA has been devised to complement the medical assessment and management of older people who are at risk for falling. We believe the major strength of the PPA is that it uses a function-based and quantitative model and thus provides a powerful tool for falls risk factor identification and the evaluation of interventions aimed at maximizing physical functioning. We contend that the PPA can provide valuable information for physical therapists and other health care professionals in both research and practice. The PPA equipment and computer program are commercially available. The current price for the comprehensive and screening versions of the PPA are US\$6,000 and US\$3,000 respectively. Further information can be obtained from Dr Lord at s.lord@unsw.edu.au or www.powmri.unsw.edu.au/FBRG/.

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Appendix 1.

Visual Acuity Conversion Chart

| Score (Line Number- Number Correct) | Converted Score |
|--|--------------------|
| 60-1 | — |
| 60-2 | — |
| 60-3 | 10.00 |
| 36-1 | 9.00 |
| 36-2 | 8.00 |
| 36-3 | 7.00 |
| 36-4 | 6.00 |
| 30-1 | 5.80 |
| 30-2 | 5.60 |
| 30-3 | 5.40 |
| 30-4 | 5.20 |
| 30-5 | 5.00 |
| 24-1 | 4.80 |
| 24-2 | 4.60 |
| 24-3 | 4.40 |
| 24-4 | 4.20 |
| 24-5 | 4.00 |
| 20-1 | 3.87 |
| 20-2 | 3.73 |
| 20-3 | 3.60 |
| 20-4 | 3.47 |
| 20-5 | 3.33 |
| 15-1 | 3.17 |
| 15-2 | 3.00 |
| 15-3 | 2.83 |
| 15-4 | 2.67 |
| 15-5 | 2.50 |
| 12-1 | 2.40 |
| 12-2 | 2.30 |
| 12-3 | 2.20 |
| 12-4 | 2.10 |
| 12-5 | 2.00 |
| 9-1 | 1.90 |
| 9-2 | 1.80 |
| 9-3 | 1.70 |
| 9-4 | 1.60 |
| 9-5 | 1.50 |
| 7.5-1 | 1.45 |
| 7.5-2 | 1.40 |
| 7.5-3 | 1.35 |
| 7.5-4 | 1.30 |
| 7.5-5 | 1.25 |
| 6-1 | 1.20 |
| 6-2 | 1.15 |
| 6-3 | 1.10 |
| 6-4 | 1.05 |
| 6-5 | 1.00 |
| 5-1 | 0.97 |
| 5-2 | 0.93 |
| 5-3 | 0.90 |
| 5-4 | 0.87 |
| 5-5 | 0.83 |
| 4-1 | 0.80 |
| 4-2 | 0.77 |
| 4-3 | 0.73 |
| 4-4 | 0.70 |
| 4-5 | 0.67 |
| 3-1 | 0.63 |
| 3-2 | 0.60 |
| 3-3 | 0.57 |
| 3-4 | 0.53 |
| 3-5 | 0.50 |

Appendix 2.

Written Report Summarizing the Physiological Profile Assessment Findings (the Name "Jane Smith" Is a Pseudonym)^a

21st January, 2003

Jane Smith

1 Australia St

Sydney, New South Wales 2000

Dear Mrs Smith,

Please find attached the report regarding your falls risk assessment at the Prince of Wales Medical Research Institute on 21st January 2003. These test results indicate that you have an increased risk of falling.

You performed well in the important tests of visual field dependence, proprioception and tactile sensitivity. In some areas, however, you were below average for your age group, so the following recommendations may be of help to you.

One or more of your vision tests were below average. Reduced vision can increase the risk of a trip over an unseen object in the environment such as steps, gutters and footpath cracks and raised edges. It is recommended that you see an eye specialist for an assessment if you have not done so in the past year. You may also benefit from wearing a single lens pair of glasses, especially when outside. It is recommended that you do not wear bifocal or multifocal spectacles, as the lower sections of these spectacles blur items at critical distances on the ground and this can lead to trips. Wearing a hat outside also improves vision by reducing glare substantially.

Your sway scores were high indicating reduced balance control. There are certain situations where you should take particular care: when walking on soft or uneven surfaces such as thick carpets and soft or rough ground. You may also be at risk of losing balance in dim or unlit areas, so avoid such areas where possible and make sure you turn the light on before walking in the house at night. Exercises can improve strength, coordination and balance. It is recommended that you increase your current level of physical activity, with a program of planned walks 3 times a week and a complementary program of group or home-based exercises. However, you should be assessed by your general practitioner prior to undertaking any exercise program. The attached home exercises could benefit you in this area. Finally, it is recommended that you wear shoes with low heels and firm rubber soles. These are best for balance.

For inquiries regarding this report, please contact the Falls and Balance Research Group at the Prince of Wales Medical Research Institute on 93822721.

Yours sincerely,

Dr Stephen R. Lord

^aReport is reproduced verbatim as shown in original report.

