Theoretical considerations in balance assessment

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Although balance control is an integral component of all daily activities, its complex and flexible nature makes it difficult to assess adequately. This paper discusses balance by examining it in relation to function and the physical environment. Balance is affected by both the task being undertaken and the surroundings in which it is performed. Different tasks and environments alter the biomechanical and information processing needs for balance control. These issues are discussed and a modification of Gentile's taxonomy of tasks is suggested for analysis of clinical balance tests, some of which are used as examples. **[Huxham FE, Goldie PA and Patla AE (2001): Theoretical considerations in balance assessment. *Australian Journal of Physiotherapy* 47: 89-100]**

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Introduction

As health professionals, physiotherapists have a specific interest in recognising and treating balance problems (Berg et al 1997). People with balance difficulties constitute a large proportion of all neurological, rehabilitation and geriatric workloads. To be effective, physiotherapists therefore need ways to assess patients, measure the outcome of treatment and predict which people, particularly amongst the older population, are at risk of falling. However, selecting an appropriate test is difficult, particularly to predict falls. Although many tests discriminate between levels of performance or even between fallers and non-fallers, very few have been shown to predict future falls. Even the carefully documented Berg Balance Scale (Berg et al 1989) may miss one-third of future fallers (Riddle and Stratford 1999), despite good sensitivity (Shumway-Cook et al 1997a). The difficulty of test selection is increased by the complex and multi-factorial nature of balance (Woollacott and Tang 1997) allowing different emphases by different therapists.

This paper treats balance as an integral component of function, stressing how balance is a product of the task undertaken and the environment in which it is performed. It will discuss how the biomechanical and information-processing aspects of both task and environment impact on balance control. Finally, it will use the framework of the taxonomy of tasks (Gentile 1987) to examine a number of common balance tests, suggesting some reasons why existing methods may fail to predict falls effectively. This will enable physiotherapists to evaluate balance assessment methods and interpret test results in light of their relevance to functional ability.

Balance and function are inextricable

Balance is not an isolated quality, but underlies our capacity to undertake a wide range of activities that constitute normal daily life. Activities such as sitting in an armchair, carrying a struggling child, cleaning a high window or running across a busy road require different and complex changes in muscle tone and activity within the balance control system. Balance cannot be separated from the action of which it is an integral component, or from the environment in which it is performed (Carr and Shepherd 1998). Balance therefore forms the "foundation for all voluntary motor skills" (Massion and Woollacott 1996, p.1).

What constitutes balance control?

Normal balance requires control of both gravitational forces to maintain posture and acceleration forces to maintain equilibrium (Massion and Woollacott 1996). Acceleration forces may be generated from within the body as the consequence of voluntary movement or

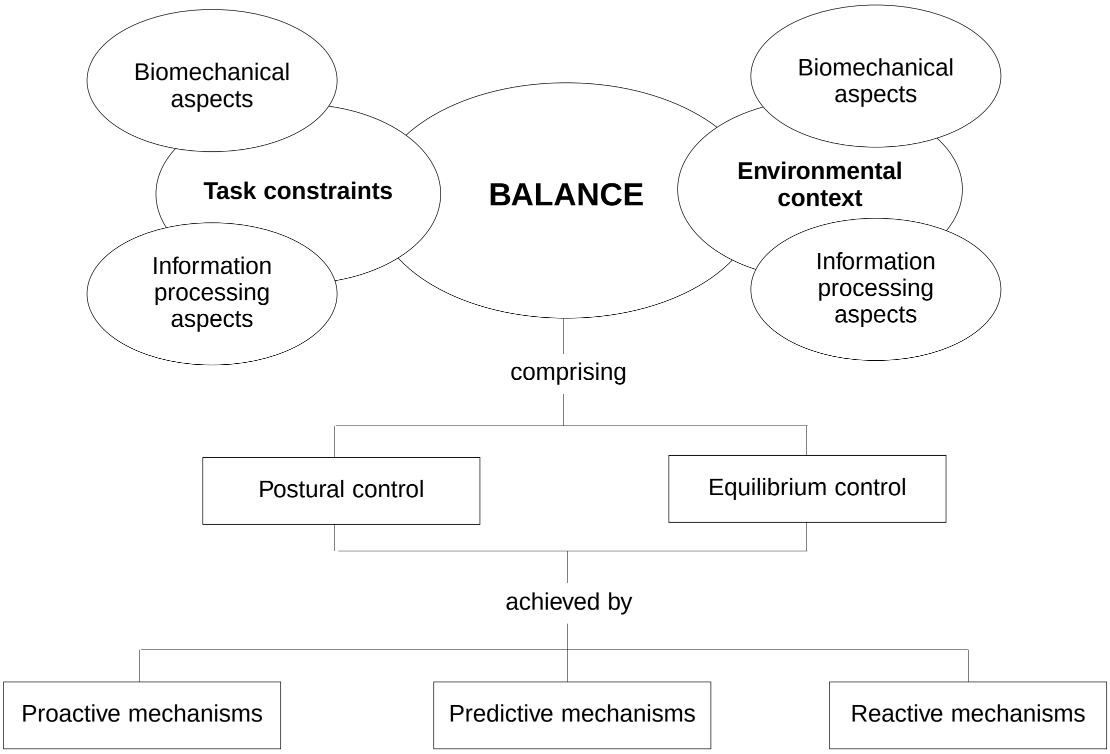

Figure 1. Determinants of functional balance.

from outside as the result of an unexpected disturbance, such as a push. Central to balance control is the need to maintain the body's centre of mass (COM) within manageable limits of the base of support (BOS) as in standing, or on track to a new BOS, as in walking or running (Winter 1995a). Together, the postural and equilibrium components of balance control ensure stability of the body during widely differing activities. The exact demands on the balance control system are determined both by the task itself and the environment in which it is performed.

Balance depends on task characteristics and environmental context

The characteristics of a task may increase or decrease the difficulty of its balance component. For example, balance is challenged less during normal walking than walking on tip-toes, in high heels or when instructed to walk very slowly, because the smaller BOS or the instruction constrain or regulate the walk.

Similarly, the environment in which the activity takes place constrains the manner in which it is performed. For example, walking in a darkened unfamiliar room will result in shorter, more cautious steps; stepping off the footpath onto a major road will use different patterns of eye and head movement than stepping down the same height from a familiar stair.

The constraints from task and environment affect motor performance in two ways (Gentile 1987) and consequently alter balance demands. First, they alter the biomechanical features of the activity. Second, they affect the amount of information that must be processed in order to achieve both balance and the motor goal. The first part of the remainder of this paper will consider the effects of task and environment on the biomechanics of balance control; the second part will examine how the information coming from both task and environment impacts on balance (see Figure 1 for schematic overview).

Biomechanical aspects of balance control

As mentioned, both postural and equilibrium control of the body (Massion and Woollacott 1996) are necessary to maintain the stability of the body against the forces of gravity and acceleration impacting upon it. As this paper will discuss, these forces are stronger and more complex during walking than when standing, because the BOS is moving (Winter 1995a).

Postural component of balance control There are two elements to the need for postural control imposed by the Earth's gravitational pull. First, even a stationary body must do work to remain upright under the force of gravity, particularly the tall human frame with its small BOS (Winter 1995b). In walking, there must always be net extensor activity in the stance limb to prevent collapse, even though one or two joints may be flexing (Winter 1995b). Second, postural control is necessary to counterbalance any movement which alters the projection of the COM of the body to the ground (the centre of gravity or COG) (Massion 1992). If the shape of the body is changed, such as by raising an arm or bending forward, the position of the COM will move closer to or beyond the boundaries of the BOS unless preventative action is taken.

Equilibrium component of balance control Equilibrium control relates to maintaining intersegmental stability of the body and its parts despite the forces acting on it (Massion and Woollacott 1996). Forces such as linear and angular accelerations affect the relationship between body parts. For example, the angular acceleration acting at the shoulder when raising an arm creates reactive moments on the trunk which must be countered by opposing postural moments before and during the movement (Eng et al 1992). Similarly, horizontal acceleration forces occur at the hip during walking. Because they act some distance from the COM, they cause unbalancing moments that would, if unopposed, cause flexion of trunk at initial contact and extension during push-off (Winter 1995a). To prevent this, the balance system produces almost equal and opposite hip moments, effectively reducing antero-posterior movement of the trunk to near zero (Winter 1995a). The amount of intersegmental stabilisation or equilibrium control necessary is determined by the speed of the focal movement and also by the mass of the body part being moved. Thus raising the arm fast or with a weight in the hand requires greater control than slow movement (Horak et al 1984). Regaining control of the trunk following a stumble is more difficult than controlling the momentum of the swinging arm because it has greater mass and inertia. Similarly, it is easier to recover from a trip if walking slowly than if walking at maximum speed.

So complex and intertwined are these forces that sometimes the postural demand to control COM and the equilibrium demand to maintain intersegmental relationships may actually conflict (Eng et al 1992). The normal control system reconciles these conflicting demands, even managing to minimise energy expenditure by utilising intersegmental dynamics. During the swing phase of walking, for instance, the inertia of the swinging thigh and shank is used to extend the knee, rather than quadriceps action (Winter 1991). Similarly, the effort required to clear an obstacle is reduced at the hip and ankle by active knee flexion and utilisation of passive forces (Patla and Prentice 1995). Thus the normal balance mechanism simultaneously meets complex, changing and sometimes conflicting demands and maximises energy efficiency.

Task influences on the biomechanical parameters of balance control The activity undertaken determines the magnitude, direction and combination of the forces of gravity and acceleration, changing its biomechanical parameters throughout the task. Further, the biomechanical challenges in standing and walking are very different because the COM lies outside the BOS for 80% of the gait cycle during walking (Winter 1995a) instead of within it as in quiet standing. The acceleration forces which act on the trunk are minimal in quiet standing, increase as a result of arm movement or manipulation and become much greater again with walking, turning and running, with or without arm movements.

These differences in biomechanical challenge may be used to classify clinical balance tests. After categorising the BOS as stationary or moving, this model sub-divides tasks in accordance with the stresses superimposed on the body. These may result from self-generated movements, such as waving or reaching, or be imposed on the body from outside, for example by a push in a crowd or movement of the BOS in a bus. Refer to Table 1 for examples using this type of classification (test details in Appendix).

Table 1. Classification of some clinical balance tests according to biomechanical demands.

	Stationary Base of Support	Moving Base of Support
Unperturbed	Timed standing Steadiness in standing	10m walk, whether timed or qualitative
Self-generated perturbations	Performance-Oriented Assessment - balance (most items) Berg Balance Scale (most items) Step Test Functional Reach Reach Test	Performance-Oriented Assessment - mobility Timed Up and Go Dynamic Gait Index Performance-Oriented Assessment – balance (turn item) Berg Balance Scale (turn item) Sensory-Oriented Mobility Assessment Instrument Functional Obstacle Course
External perturbation	Performance-Oriented Assessment – balance (sternal thrust item) Postural Stress Test Shoulder Tap Test	
Sensory manipulation or perturbation	Clinical Test of Sensory Integration and Balance	Sensory-Oriented Mobility Assessment Instrument

Classifying balance tests in this way highlights some of the biomechanical differences in balance control involved in perturbed and non-perturbed activities. It should be noted that some tests do not fall entirely in one class because they have a number of components, eg Berg Balance Scale (BBS) (Berg et al 1989) and Performance-Oriented Assessment (B-POMA) (Tinetti 1986). However, this classification has significant limitations because it fails to recognise that the environmental context of a task will influence its biomechanical parameters. It further neglects the role played by the amount of information to be processed from the task itself, and from its environmental context.

How environmental context influences the biomechanical parameters of balance The environmental context of a task can alter its biomechanical parameters in two ways (Patla 1997). Walking patterns are likely to demonstrate different kinematics and kinetics to accommodate to walking on sand, in water or over slippery surfaces. The size or compliance of the support surface in standing has been demonstrated to alter the balance strategies used (Nashner 1989) and the ability to stand independently (Cohen et al 1993).

The second type of environmental effect on motor performance and hence balance may be seen in avoidance strategies such as walking around an obstacle, running to avoid an oncoming car or increasing stride to step over a puddle. In detailing the roles of vision for locomotor control, Patla recognises the importance of environmental context in balance control during walking (Patla 1997) and suggests that balance is achieved via two main essentials. The first and more major essential utilises two types of learned *proactive* mechanisms to reduce or counteract stresses acting on the body. The second essential consists of largely automatic *reactive* mechanisms that respond to failures of proactive components or to unexpected external perturbation.

The first category of *proactive balance mechanisms* is based on the visual system. Information about environmental conditions and changes is constantly received through the eyes and interpreted in the light of experience for its impact on stability (Patla 1997). Thus we step around or over perceived obstacles, reduce our walking speed if the surface appears to be slippery, and maintain a higher degree of alertness in potentially hazardous situations such as rough terrain or cluttered areas. These appropriate adjustments generally prevent the need to recover from the stronger forces that would be imposed by a stumble, slip or trip.

As well as visually-based proactive balance control evaluating the external environment, a second form of proactive control considers the forces acting on and within the body. Sometimes referred to as *predictive balance control*, this maintains intersegmental stability within the body and between the body and the support surface (Patla 1995). It is dependent upon an accurate internal representation of the body and a learned awareness of how any movement or muscle action will alter these relationships (Nashner 1989).

Predictive control of the forces acting on the body is largely achieved by anticipatory postural adjustments (Patla 1995). These patterns of muscle activity commence prior to most voluntary or focal movements (Massion and Woollacott 1996). The type and magnitude of anticipatory postural adjustments are determined by the direction and speed of focal movement (Aruin and Latash 1996). The initial response is not based on sensory input but rather on what experience has taught will be the amount and direction of destabilisation produced by the focal movement (Patla 1995). Other postural accompaniments (Frank and Earl 1990) or reactional adjustments (Bouisset and Zattara 1987) act to reinforce the anticipatory postural adjustments accompanying and following on the voluntary movement. Unlike anticipatory postural adjustment, they utilise somatosensory and kinaesthetic input to guide the extent and type of their actions, thereby compensating for any inadequacies in anticipatory control. They act both to steady body parts for movement and to stabilise the body against gravity (Massion 1992). In walking, the anticipatory postural adjustments include the commencement of COM movement towards the new BOS provided by the new stance leg before the swing leg is moved (Massion 1992).

In these ways, the balance system proactively monitors the external environment and predicts the effects of forces generated by voluntary movement on the body, making the adjustments necessary to maintain posture and equilibrium in anticipation of need. It is only when these adjustments fail or an unexpected destabilisation occurs that the emergency back-up system of *reactive* balance responses is called in for crisis management (Patla 1995).

Reactive balance control consists of both short and long latency postural reflexes of a type appropriate to the particular stimulus (Nashner 1980). In standing, minor perturbation frequently requires only the response of an ankle strategy, a distal-to-proximal synergy of either anterior lower limb muscles for posterior destabilisation or posterior limb muscles for anterior destabilisation. Stronger perturbation or a narrow support surface may require a hip strategy in which much larger multi-joint movements are used to bring the COM back within the BOS (Nashner 1989). It was believed that a step strategy, in which the BOS is actually shifted by taking a step away from the perturbation, only occurred with very marked instability or strong perturbation. However earlier works describing these responses had actually constrained the foot position, either implicitly or explicitly. Recent research suggests that a step strategy may often be preferred for even minor perturbation (Maki and McIlroy 1997).

In summary, the biomechanical demands on balance are a product of factors relating to the motor task itself and to aspects of its environmental context. The normal balance system is believed to meet these varied demands by a mixture of proactive visual and predictive mechanisms, with reactive processes playing an important role when proactive ones fail or perturbation is unexpected.

It is apparent from Table 2 that the vital proactive balance mechanisms used to navigate and plan to avoid obstacles are scarcely assessed. This suggests that the tests listed are likely to be limited in their ability to predict how well people will perform in the world outside the physiotherapy department. As emphasised by Patla, stability is particularly maintained by accommodating to or avoiding potential stresses, with reactive mechanisms constituting the backup system (Patla 1997). Although predictive control of forces is assessed by clinical balance tests that use self-generated perturbations such as the Berg Balance Scale (BBS) (Berg et al 1989) and the Dynamic Gait Index (Shumway-Cook and Woollacott 1995), these require little or no use of the visual component of proactive balance control. Two tests do include this component to some extent by requiring the subject to plan a course and to traverse surfaces of different compliance. The Functional Obstacle Course (FOC) (Means et al 1996) includes obstacles to be stepped over or around, necessitating visual evaluation of the size and location of the obstacles and planning of how best to negotiate them. The Sensory-Oriented Mobility Assessment Instrument (SOMAI) course

(Tang et al 1998) is repeated a second time with peripheral vision occluded by goggles. This challenges and assesses the person's ability to use other sensory modalities to compensate for reduced vision. Although both tests represent advances in the use of vision for proactive balance, the environments in which they are performed are still static and so the degree of challenge for visual proactive control is less than in open and dynamic situations such as a crowded supermarket. Conditions such as those in a supermarket are more complex because of both the amount and changing nature of sensory information present. It is probable that failure to recognise the impact of this on the balance control system contributes to the limited predictive ability of balance tests.

Having discussed how the task and the environment affect the biomechanical aspects of balance control, consideration will now be given to how the need to process information from these areas also impacts on the control of balance.

Information processing aspects of balance control

In order to meet the biomechanical challenges of task and environment, the balance mechanism requires adequate sensory input, efficient central processing and a strong effector system of muscles and joints (Horak et al 1989). A redundancy of sensory information is normally available. Visual information about the near and far environment allows us proactively to avoid obstacles (Patla 1997). Visual information from the environment combines with memory in a process called cognitive-spatial mapping to enable us to plan a route to places out of sight (Patla 1997). Peripheral visual information about limb position assists obstacle clearance (Patla 1997). Finally, optic flow, information from peripheral vision as we move, tells us about our movement in walking (Patla 1997). In addition, vestibular information concerning our relationship with vertical, and proprioceptive and somatosensory messages detailing the relative positions of our body parts to themselves and the support surface make up the sensory input to the balance control mechanism.

This wealth of sensory information streams into the central processing regions of the central nervous system. Here it must be integrated and weighted in light of experience to establish its importance or relevance and an appropriate motor response including balance reactions be selected and implemented. Importantly, the capacity of the central processing regions is not infinite. This is demonstrated by reduced performance of secondary tasks shown by dual-task paradigms (Abernethy 1988). Further limitations may appear with ageing (Chen et al 1996) or pathology (Morris et al 1995).

Balance control, although performed at an unconscious level, is not a fully automatic process (Ebersbach et al 1995, Teasdale et al 1993). The level of attention required to maintain postural control in a challenging position increases from sitting to standing to walking and in the elderly (Chen et al 1996, LaJoie et al 1996, Teasdale et al 1993) and in those with a history of falls (Shumway-Cook et al 1997b). Older people also choose to respond to a secondary auditory task at the more stable initial contact phase of the gait cycle, unlike young subjects who respond close to the stimulus regardless of the phase (LaJoie et al 1996). It is therefore important to consider other competing processing demands of the environment when analysing the ability of an individual to balance effectively.

Environmental influences on information processing for balance control The amount of information processing required depends on the complexity of the environment and whether it changes throughout the activity. Walking along a carpeted, well-lit and empty corridor requires less processing than walking in a similar corridor filled with chairs and pillars, and with several different floor surfaces. Despite greater initial processing demand in the second condition, the information present is stable over time and allows monitoring to reduce during task performance. This means the attentional demand of a task in such stable or closed environments reduces (Gentile 1987). Furthermore, because the surroundings are fixed, the motor activity does not have to fit in with external timing but can be done at preferred speed.

However, most environments comprise both fixed and varying elements. If the above-mentioned empty corridor were to fill with a number of people walking towards the subject, information processing demand would increase enormously. In order to prevent collisions, the subject must now calculate other people's paths and plan their own to avoid them. It is

Table 2. Ability of some balance tests to recognise constraints from task and environmental context.

Balance test	Task conditions	Environmental conditions	Balance mechanisms used
Berg Balance Scale	closed	simple and stable	predictive; some use of vision proactively to locate object to pick up
Clinical Test of Sensory Integration and Balance	closed	simple and stable (items 1 & 2) simple and active (items 3-6)	predictive
Dynamic Gait Index	closed	simple and stable	proactive to locate stairs and obstacles; predictive
Functional Reach	closed	simple and stable	some use of vision; mainly predictive
Functional Obstacle Course	closed	complex but stable	proactive to evaluate obstacles and surface changes; predictive
Performance-Oriented Assessment – balance and mobility	closed	simple and stable	mainly predictive; proactive to locate object to pick up; one item tests reactive balance
Reach Test	closed	simple and stable	some use of vision; mainly predictive; repetitive timed nature of reach increases degree of challenge relative to Functional Reach test.
Sensory-Oriented Mobility Assessment Instrument	closed	complex but stable within trials; visual condition changes between trials	proactive to evaluate obstacle and surface changes; predictive
Step Test	closed	simple and stable	some use of vision; mainly predictive
10 metre walk	closed	simple and stable	predictive
Timed standing	closed	simple and stable	predictive

probable that such complex central calculations distract attention from maintaining balance. This may be seen clinically when stroke patients undergoing rehabilitation can walk in a quiet and closed environment but lose their balance if distracted. Not only is more attention required but the ongoing nature of path calculations and predictions means the demand on central processing does not decrease (Gentile 1987). Thus open contexts changing in time differ markedly from stable or fixed environments, however complex.

Many activities depend even more intimately on the environment for their performance. These are tasks in which the timing of the task is directly linked to the environment, such as catching a ball, moving about on a crowded bus or stepping onto an escalator. The timing constraint requires more complex calculations and predictions and further increases the central processing load.

Task influences on information processing for balance control The central processing area handles complex information not only from the environmental context but also from the task itself. Like environments, complicated tasks require more information processing than simple ones. As with closed environments, closed tasks whose characteristics do not change from one trial to another require less information processing with practice (Gentile 1987). The intimate relationship between task and environment that occurs when the task must be timed to environmental factors has been noted above. When performance depends on external timing, demand for central processing increases because success depends on predicting future spatial relationships of, for example, a bat and a ball or the hand reaching for a suitcase on a revolving carousel (Gentile 1987).

In summary, the need to process information related to task and environment may compete for limited central resources and hence impact adversely on balance control. Frail elderly or patient groups may be unable to walk and concurrently talk or carry objects without impairing their balance (Lundin-Olsson et al 1997, Morris and Iansek 1997). Similarly, they may be unable to manage in new or dynamic environments. Externally paced activities, dual task performance and complex or changing environments provide greater challenge in information processing.

Understanding the biomechanical and information processing demands imposed by task and environmental context allows us to evaluate their probable impact on motor performance and balance. Applying Gentile's framework of task and environmental demands (Gentile 1987) to some existing balance tests helps to evaluate their strengths and limitations (see Table 2). Utilising this model, Table 2 provides a more comprehensive method of classifying balance tests. It can be seen that although several of the tests include more complex environments (eg FOC (Means et al 1996), SOMAI (Tang et al 1998)), there are as yet no methods that include moving or open environments. It appears likely that our current inability to evaluate this highest level of balance objectively contributes to the poor predictive value of available tests. Unless or until some test can incorporate open environments, clinicians should be aware that the balance assessments they are using for objective measurement have limitations. As clinical assessment is a tool for treatment and not an end in itself, this knowledge reinforces the need to practise mobility in open environments. Examples of open tasks in an active environment include: pushing a loaded trolley in the supermarket; pulling different coins out of a purse while crossing the road; walking while having a conversation and putting on sunglasses.

Type of practice affects motor learning

Assessment, as stated, is only a component of treatment. As well as the biomechanical and information processing aspects of task performance, another aspect of task has important implications for treatment - the manner in which it is learnt. Practice type affects motor learning (Gentile 1987). If each trial is practised in the same way, the resulting skill, probably with its underlying balance adjustments, will be fine-tuned to a single skilled production and motor learning of a reproductive nature will occur (Gentile 1987). However, when practice is varied by changing aspects of the environmental context or the task, the motor skill that develops is more flexible and generative in type (Gentile 1987). Generative motor skill learning resembles a kind of motor problem solving ability. The difference between the two types of skill learning is particularly significant clinically. As balance is a flexible and varying integral of all movement, it would seem appropriate that it should be retrained in a generative manner. For example, practice for a stroke patient reaching to a target to improve balance can be broadened by changes in speed, instruction, support surface compliance, hand position, foot configuration and target size, shape and position. These changes incorporate different biomechanical and information processing components of task and environment. The benefit of varied balance practice has been demonstrated in a randomised controlled study of training sitting balance in chronic stroke (Dean and Shepherd 1997). Subjects who were challenged by varied reaching tasks showed improvement in not only sitting balance but also sit-to-stand, an action with a similar biomechanical component. These results demonstrate the ability of balance skills gained through flexible practice to generalise to other activities.

Conclusion

The inextricability of balance, function and the environment has been clearly demonstrated in recent years. Physiotherapists frequently assess and treat people unable to maintain adequate stability for all the goal-directed motor tasks of a normal active life. The original taxonomy of tasks (Gentile 1987) provides a structure to examine the complexity of these tasks and criteria for normal balance performance. Some common balance measures have been evaluated as examples of using these criteria. Consideration of these criteria during assessment will help the clinician establish the functional level of patients' balance and guide treatment to maximise functional recovery.

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Appendix

Listed below are many of the methods of assessing balance commonly used in the clinics, with brief descriptions of how they are performed and scored.

Berg Balance Scale (BBS) (Berg et al 1989)

Task: There are 14 items performed in standing and graded from 0 (unable) to 4 (independent), with a maximum score of 56. Items are: sitting unsupported; rising from and sitting down in a chair; transfer from chair to chair; standing unsupported; standing eyes closed; standing feet together; tandem standing; single leg stand; turning trunk with feet flexed and also turning 360 degrees; picking up an object off the floor; stepping one foot up and down off a step and a forward reach. The scale has sensitivities of 53% (Thorbahn and Newton 1996) and 91% when used with history of imbalance (Shumway-Cook et al 1997a).

Clinical Test of Sensory Integration and Balance (CTSIB) (Shumway-Cook and Horak 1986)

Task: The subject is tested for ability to stand still under six permutations of sensory input so that the capacity to compensate for missing or misleading input can be assessed. The conditions are: eyes open, firm surface; eyes closed, firm surface; eyes open but visual conflict provided through a hood, on firm surface; eyes open, compliant surface; eyes closed, compliant surface; visual conflict, compliant surface. Subjects are timed to a maximum of 30 seconds in each condition.

Dynamic Gait Index (DGI) (Shumway-Cook and Woollacott 1995)

Task: The subject is asked to walk continuously on a level surface. Self-initiated perturbations are performed on command approximately every five feet as follows: walk normally; walk fast; walk slowly; walk with head turns from side to side; then neck flexion/extension; walk and then pivot turn and stop; walk and step over a shoebox and 'slalom' around two cones. The final item is assessment of walking up and down stairs. All items are scored from 1 (severely affected) to 3 (normal), to a total of 24 points. Clear definitions are given for scoring each item. Discriminates between fallers and non-fallers but predictive ability not known.

Functional Obstacle Course (FOC) (Means et al 1996)

Task: The FOC involves walking at preferred speed and with an aid, if normally used, over four different surfaces (artificial turf, shagpile carpet, pinebark and sand) up and down a standard 1:12 ramp and up and down two sets of steps. One set of steps has 7.6cm risers and the other 15.2cm risers. Subjects must also rise from a soft, armless chair, open a door, perform a slalom course around eight large plastic cones without stepping outside a boundary line and step over three cylindrical bolsters of 10.2, 15.2 and 20.3 cm diameter. These are aligned parallel and 61cm apart. Subjects cover approximately 106m in the test and are timed for the whole test. Qualitative assessments are also made of each of the 12 component manoeuvres, following clear guidelines. Each item is scored 0 (unable or refuses) to 3 (smooth motion and no assistance from neighbouring support or person). Shown to discriminate between fallers and non-fallers but predictive ability not assessed.

Functional Reach (FR) (Duncan et al 1990)

Task: In comfortable barefoot stance, the subject is asked to raise the right arm, fist closed, to approximately 90 degrees and then to reach forwards as far as possible without losing balance or moving the feet. The distance between the position of the third metacarpal in each position is the Functional Reach. Reduced ability to reach has shown increases in future falls with odds ratios of 8.2 if unable to reach at all and 4 if able to reach < 15.2cm (Duncan et al 1992).

Performance-Oriented Mobility Assessment – balance (B-POMA) (Tinetti 1986)

Task: Tinetti's original performance-oriented assessment has both a balance and mobility or gait section. However, as some projects use the sections separately, they will be discussed separately here. The balance section examines the ability of subjects in 13 tasks and requires a judgment as to whether they are performed normally (1 point), using an adaptive response (2 points) or abnormally (3 points). Thus the score for a completely normal performance is 13 and higher scores represent poorer balance. The items are: sitting balance; rising from a chair; immediate standing balance; standing balance with feet together eyes open and then eyes closed; ability to turn 360 degrees on the spot and withstand a nudge on the sternum; head turning with feet together; single leg balance; back extension; reaching up and bending down and sitting down.

Performance-Oriented Mobility Assessment – gait (M-POMA) (Tinetti 1986)

Task: The mobility section of Tinetti's problem-oriented assessment is a qualitative evaluation of mainly unperturbed walking. The subject walks at preferred pace with a walking aid, if used, while the examiner observes the gait for nine qualities: initiation of gait; step height; step length; step symmetry; step continuity; path deviation; trunk stability; walk stance and turning while walking. Scores are 1 for normal and 2 for abnormal or compensatory and the criteria for scoring are clearly defined.

Postural Stress Test (PST) (Wolfson et al 1986)

Task: The subject stands with feet apart wearing a padded waistband that is attached at the back to a wall-mounted pulley system, such as found in most physiotherapy departments. An unexpected backward perturbation is applied by one of a graded series of weights standardised to a percentage of body weight. The weight is applied abruptly. Results consider not only the weight used but the resultant strategy used by the patient. Able to discriminate between fallers and non-fallers but predictive ability not investigated.

Reach Test (Goldie et al 1990)

Task: Developed for hemiplegic subjects, this test requires that the subject repetitively reaches from a target close to the ipsilateral greater trochanter to touch a second target positioned at waist level in front of the opposite hip. This second target is placed 15cm beyond the length of the extended arm. The number of repetitions achieved in 60 seconds constitutes the score.

Sensory-Oriented Mobility Assessment Instrument (SOMAI) (Tang et al 1998)

Task: The SOMAI incorporates the following mobility items: rise from chair; unperturbed walk; reach high to remove a piece of tape off the wall and then low to place it on the wall at knee level; turn 180 degrees and walk along a carpeted walkway which incorporates two foam cushions underlying it and return to the chair. The SOMAI is performed twice, once with normal vision and once with peripheral vision occluded. Performance on each component is qualitatively evaluated and rated from 0 (normal) to 3 (required assistance for safety), consequently a perfect score would be 0. The test is not timed. Ability to discriminate or predict fallers not investigated.

Shoulder Tap Test (Pastor et al 1993)

Task: The subject stands facing away from the examiner, who advises: "I am going to tap you backwards; I won't let you fall" and then applies a quick tug to both shoulders of sufficient force to destabilise the subject. The test is graded according to whether an ankle strategy, a step response or no postural response ('plank' reaction) is evoked. Failed to discriminate people with Parkinson's disease who fell from those who did not (Bloem et al 1998).

Step Test (Hill et al 1996)

Task: The subject stands on one leg then steps the other on then off a 7.5cm block placed 5cm in front of the feet, as many times as possible in 15 seconds. The task is then repeated using the other leg.

Timed standing with the feet in different configurations (Bohannon et al 1984)

Task: The task difficulty progresses from standing with feet apart through feet together, step stance and tandem stance to single leg stance. Each position is timed, usually to a maximum of 30 seconds. The one legged stance component has shown a positive predictive value for injurious falls of 31% (Vellas et al 1997).

Timed 'Up and Go' (TUG) (Podsiadlo and Richardson 1991)

Task: On the command "Go", the subject rises from a standard chair, walks three metres, turns and walks back to the chair. Timing starts when the command is given and ceases when the subject is again sitting in the chair.