Facultat de Psicologia, Ciències de l'Educació i de l'Esport Blanquerna
Universitat Ramon Llull

Liverpool Hope University

TESI DOCTORAL

Functional Performance in Physically Frail Community Dwelling Older Adults

Maria Giné Garriga
2010

Directors: Dra. Míriam Guerra i Dr. Viswanath Unnithan

Universitat Ramon Llull

TESI DOCTORAL

Títol:

Functional Performance in Physically Frail Community Dwelling Older Adults

Realitzada per **Maria Giné Garriga**

en la **Facultat de Psicologia, Ciències de l'Educació i de l'Esport Blanquerna. Universitat Ramon Llull**

i en el **Departament de Ciències de l'Activitat Física i l'Esport**

Dirigida per la **Dra. Míriam Guerra Balic** i el **Prof. Viswanath B. Unnithan**

C. Claravall, 1-3
08022 Barcelona
Tel. 936 022 200
Fax 936 022 249
E-mail: urlsc@sec.url.es
www.url.es

Facultat de Psicologia, Ciències de l'Educació i de l'Esport Blanquerna
Universitat Ramon Llull

Liverpool Hope University

DEPARTMENT OF PHYSICAL ACTIVITY AND SPORT SCIENCES
FPCEE BLANQUERNA
UNIVERSITAT RAMON LLULL

FUNCTIONAL PERFORMANCE IN PHYSICALLY FRAIL COMMUNITY DWELLING OLDER ADULTS

EUROPEAN DOCTORATE

Thesis presented by:
Maria Giné Garriga

To obtain the degree of doctor by the FPCEE Blanquerna, Universitat Ramon Llull

Supervised by:
Dr. Míriam Guerra and Prof. Viswanath B. Unnithan

Barcelona 2010

Aquesta Tesi Doctoral ha estat parcialment finançada per l'Institut d'Investigació en Atenció Primària Jordi Gol i l'Institut Català de la Salut, que va concedir la *beca per a la capacitació en investigació i realització del doctorat a l'atenció primària,* corresponent a la convocatòria 2008.

"El coneixement científic és el resultat d'una conversa entre dues converses: l'experiència (conversa amb la naturalesa) i la reflexió (conversa amb un mateix)".

Wagensberg, J. (2002)

Agraïments - Acknowledgements

El meu interès envers la gent gran va nèixer amb la meva primera feina com a fisioterapeuta a un centre residencial. Des de llavors, tot i haver canviat el meu exercici professional, aquest col·lectiu de persones no m'ha deixat de sorprendre, admirar i motivar. Dedico i agraeixo doncs en primer lloc aquest estudi a totes les persones grans amb les qui he tingut l'oportunitat de treballar i de les qui tantes coses he après, ja que m'han sabut evocar en tot moment les ganes, l'energia i l'esforç de tirar endavant aquesta tesi doctoral.

D'altra banda, i per raons diferents, vull agrair la Dra. Míriam Guerra i el Prof. Vish Unnithan el recolzament generós i el molt temps dedicat, com a directors d'aquesta tesi doctoral. Ells han sabut com encaminar l'estudi, reconduir-lo en determinats moments de confusió i fer del treball un espai agradable i una oportunitat continuada d'aprendre.

El desenvolupament d'aquest estudi no hagués estat possible sense el suport de l'Àmbit d'Atenció Primària de Barcelona Ciutat de l'Institut Català de la Salut, on tinc el plaer de treballar. M'agradaria agrair molt especialment el recolzament de la Gerència, la Unitat de Suport a la Recerca de Barcelona, la Unitat de Rehabilitaió de Drassanes, i l'Institut d'Investigació en Atenció Primària Jordi Gol.

L'estudi tampoc s'hagués pogut dur a terme sense la col·laboració de la Unitat de Rehabilitació de l'Hospital Vall d'Hebron amb la col·laboració desinteressada de la Dra. Miró, la Dra. Pagès, la Dra. Rodríguez, i la Sra. Solé, que en el seu moment em van mostrar les característiques i em van permetre fer ús del dinamòmetre isocinètic i la plataforma d'equilibri. Ni sense la col·laboració de l'Atenció Primària Vallcarca - Sant Gervasi, amb l'empenta de la Dra. Jiménez, la Sra. Palacios, la Sra. Villafuerte, i la Sra. Martínez.

Ni sense l'ajuda d'en Marc Marí i el Dr. Greg Atkinson que han estat essencials per l'assessorament estadístic.

Com també ha estat essencial la revisió crítica dels treballs i els consells encertats del Dr. Todd Manini.

Així com el recolzament de la Facultat de Psicologia, Ciències de l'Educació i de l'Esport Blanquerna, i de la Liverpool Hope University.

Així mateix, la col·laboració de la Carme Martin, companya de feina i amiga, i la tutorització del Dr. Carlos Martin han estat molt importants pel correcte desenvolupament de l'estudi.

Un agraïment especial a tots els amics i amigues que han seguit de prop aquest llarg procés de construir una tesi doctoral. Per tot el temps que us he robat, i pels vostres ànims, paciència, comprensió i empatia. I un agraïment molt especial a l'Amanda a qui tinc molt present i a qui agrairé sempre la seva amistat.

Gràcies també a la Paula, la Marina, l'Anna, la Maria, la Marta, la Lisette i la Sandra, amb les qui he compartit un interès comú per la recerca i amb les qui tantes vegades m'he recolzat durant el transcurs d'aquest llarg camí.

I finalment, nogensmenys important ha estat el recolzament de la família. Així, gràcies pare, mare, Xavi, Clara, Laura i el petit David, Ricard i Ana, i David per haver estat una empenta constant i haver-me sabut atiar en els moments de dubte. David gràcies especialment per la teva infinita paciència i suport incondicional. I sense haver nascut encara, gràcies també a l'Arnau per donar-me el motiu definitiu per finalitzar aquest treball. Us dedico aquesta tesi amb molta il·lusió.

List of publications arising from the thesis work

Giné-Garriga M, Guerra M, Marí-Dell'Olmo M, Martin C, Unnithan VB. Sensitivity of a modified version of the 'Timed Get Up and Go' Test to predict fall risk in the elderly: a pilot study. *Archives of Gerontology and Geriatrics* 2009; 49: e60-66. (doi:10.1016/j.archger.2008.08.014).

Giné-Garriga M, Guerra M, Manini TM, Marí-Dell'Olmo M, Pagès E, Unnithan VB. Measuring Balance, Lower Extremity Strength and Gait in the Elderly: Construct Validation of an Instrument. *Archives of Gerontology and Geriatrics* [In press].

Giné-Garriga M, Guerra M, Pagès E, Manini TM, Jiménez R, Unnithan VB. The effect of functional circuit training on physical frailty in frail older adults: a randomized controlled trial. *Journal of Aging and Physical Activity* [In press].

Grants arising from the thesis work

Title of the project: Avaluació de l'efectivitat d'un programa d'equilibri i força d'extremitats inferiors per millorar els paràmetres físics de fragilitat en gent gran independent: Assaig clínic aleatori controlat.
Financing administration: Institut d'Investigació en Atenció Primària (IDIAP) Jordi Gol i Institut Català de la Salut.
Amount: 9015€
Duration: 2009-2011

Title of the project: Avaluació de l'efectivitat d'una intervenció en el Centre de Rehabilitació de Drassanes per millorar els paràmetres físics de fragilitat en gent gran independent: Assaig clínic aleatori controlat.
Financing administration: Unitat de Suport a la Recerca de l'Àmbit d'Atenció Primària de Barcelona, Institut Català de la Salut.
Amount: 3000€
Duration: 2009-2010

Research awards arising from the thesis work

Title of the project: Avaluació dels factors de risc de caiguda en gent gran independent: validació d'un instrument de mesura.
Financing administration: FPCEE Blanquerna. Universitat Ramon Llull
Amount: 2000€
Year: 2008

Other publications

Giné-Garriga M, Guerra M, Chamarro A, Martin C, Marí M. Reliability of the ACEMFEI test: quantitative and qualitative approach. *Medicine and Science in Sports and Exercise* 2007; 39 (5): 357.

Giné-Garriga M, Guerra M, Marí M, Martin C, Unnithan V. Validation of the ACEMFEI Test to prevent the risk of falls in the elderly. *Medicine and Science in Sports and Exercise* 2008; 40 (5): 373.

Giné-Garriga M, Guerra M, Pagès E, Manini TM, Marí-Dell'Olmo M, Jiménez R, Unnithan VB. The effect of functional circuit training on balance and strength in physically frail older adults. *Medicine and Science in Sports and Exercise* 2010; 42 (5): 105.

Congresses participation arising from the thesis work

Giné-Garriga M, Guerra M. Reliability of a new test to assess physical parameters related to falls in the elderly. Poster: 11th annual Congress of the European College of Sports Science. Lausanne, 2006.

Giné-Garriga M, Guerra M. Fall risk assessment in the elderly. Poster: Simposi Internacional: Evidència científica i investigació en caigudes *Prevention Of Falls Network Europe* (PROFANE). Barcelona, 2006.

Giné-Garriga M, Guerra M, Chamarro A, Martin-Borràs C, Marí M. Reliability of the ACEMFEI test: quantitative and qualitative approach. Poster: 54th Annual Congress of the American College of Sport Medicine. New Orleans, 2007.

Giné-Garriga M, Guerra M, Unnithan VB. Validació de la prova ACEMFEI: avaluació de la coordinació, l'equilibri, la marxa i la força d'extremitats inferiors en gent més gran de 65 anys per prevenir el risc de caigudes. Oral presentation: II Jornada: Mobilitat, caigudes i exercici físic en les persones grans. Barcelona, 2008.

Giné-Garriga M, Guerra M, Marí-Dell'Olmo M, Möller M, Martin-Borràs C, Beltran A, Unnithan VB. Fiabilidad de una versión modificada del test 'Timed get up and go' para predecir el riesgo de caídas en gente mayor. Oral presentation: XVIII Jornada d'actualització en Rehabilitació Geriàtrica. Societat Catalana de Medicina Física i Rehabilitació. Barcelona, 2008.

Giné-Garriga M, Guerra M, Marí M, Martin C, Unnithan VB. Validation of the ACEMFEI test to prevent the risk of falls in the elderly. Poster: 55th Annual Congress of the American College of Sport Medicine. Indianapolis, 2008.

Giné-Garriga M, Guerra M, Möller M, Martin C, González J, Unnithan VB. A balance and lower body strength-based program to improve frailty physical components in older adults who live at home: A pilot randomized controlled trial. Oral Presentation: III Congreso Internacional de Actividad Físico Deportiva para mayores. Málaga, 2009.

Giné-Garriga M, Guerra M, Pagès E, Manini TM, Marí-Dell'Olmo M, Jiménez R, Unnithan VB. The effect of functional circuit training on balance and strength in physically frail older adults. Oral presentation: 57th Annual Congress of the American College of Sport Medicine. Baltimore, 2010.

CONTENTS

TABLES INDEX

GLOSSARY

Active life expectancy. Number of years of life spent without significant disease or disability (Fries & Crapo, 1981). Katz et al. (1983) adopted a more positive tone by defining it as the number of expected years of physical, emotional, and intellectual vigour or functional well-being.

Assessment. Refers to the evaluation risk.

Balance. Process by which we control the body's centre of mass with respect to the base of support, whether it is stationary or moving. Is a physical concept where the forces and moments counteract with precision (Gagey & Weber, 2001). Balance, both static and dynamic, is achieved thanks to interaction between sensory receptors located in the vestibular, visual and somatosensory systems, the Control Nervous System (CNS), and the musculoskeletal reflex arcs (Lázaro et al., 2005). The coordinated action of these anatomic structures is responsible for maintaining the body's centre of gravity (CoG) within its base of support in order to avoid a possible fall.

Bias. May result from flaws in the design of a study or in the analysis of results and may result in either an underestimate or an overestimate of the effect.

Cadence. The number of steps per unit of time.

Case-control study. A study in which the effects of an exposure in a group of patients (cases), who have a particular condition, are compared with the effects of the exposure in a similar group of people who do not have the clinical condition – the latter is called the control group.

Centre of mass. The point at which all the mass of a body may be considered to be concentrated in analyzing the forces that act on it and the body's motion. Also referred to as the CoG because the gravitational force due to the weight of the body also acts through this point.

Cohort study. Follow-up of exposed and non-exposed groups of patients – the exposure is either a treatment or condition – with a comparison of outcomes during the time followed-up.

Co-interventions. Interventions/treatments other than the treatment under study that are applied differently to the treatment and control groups.

Community dwelling older people. Older people living independently in their own homes or in a communal setting without health care facilities.

Co-morbidity. Co-existence of a disease or diseases in a study population in addition to the condition that is the subject of study.

Confidence interval (CI). The ranges of numerical values in which we can be confident that the population values being estimated were found. Confidence intervals indicate the strength of evidence; where confidence intervals are wide they indicate less precise estimates of effects.

Double-support time. The time during the gait cycle when both feet are in contact with the ground.

Dynamic contraction. Once the muscle changes its length, an external task is performed that can be measured using data of strength and distance. With regard to tension produced in the muscle during contraction, this can be: (a) *Isotonic* if the contraction strength is kept constant and invariable during the entire movement; or (b) *allodynamic* if tension varies throughout the entire action (Manso et al., 1996). In relation to speed of tension, there is: (a) *isokinetic contraction* if movement speed is invariable; or, on the contrary, (b) *heterokinetic contraction* if movement speed changes (Manso et al., 1996). As regards direction of change in muscle length, the action can be (a) *concentric* when there is shortening of muscle fibres because resistance is lower than muscle power, which means positive working; or (b) *eccentric* when the action produces the lengthening of muscle fibres because resistance is higher than muscle power, which means negative working (Perrin, 1993).

Effectiveness. The extent to which interventions achieve health improvements in real practice settings.

Efficacy. The extent to which medical interventions achieve health improvements under ideal circumstances.

Extrinsic risk factors. Factors that are external to the individual that elevate the risk for falls during the performance of daily activities.

Fall. Event whereby an individual comes to rest on the ground or another lower level with or without loss of consciousness.

Follow-up. Observation over a period of time of an individual, group or population whose relevant characteristics have been assessed in order to observe changes in health status or health-related variables.

Functional capacity. Reflects an older adult’s ability to perform physical activities of daily life with relative ease (Rikli & Jones, 1999).

Gait cycle. The time between the first contact of the heel of one foot with the ground and the next heel-ground contact with the same foot.

Gold standard. A reference standard for evaluation of a diagnostic test. For the purposes of a study, the gold standard test is assumed to have 100 per cent sensitivity and specificity. Choice of the gold standard must therefore be evaluated in appraising a diagnosis study.

Health professional. Includes nurses, physiotherapists, allied health professionals and doctors.

Incidence. The number of new cases of illness commencing, or of persons falling ill during a specified time period in a given population.

Injurious fall. Refers to a fall resulting in a fracture or soft tissue damage that requires treatment.

Intrinsic risk factors. Age- or disease-related changes occurring within the older adult.

Isometric contraction. When resistance is equal to the capacity of contraction, and therefore there are no changes in muscle length. The maximum isometric strength that a muscle can develop depends on its surface of section. Variations in this value depend, among other things, on the proportion of contractile fibres and connective tissue, on the proportion of Type 2 fibres (their contraction speed is 1.5 times higher than Type 1 fibres), and on the characteristics of nervous arousal (Jiménez & Aguilar, 2000).

Linear mixed model. Mathematical approach that can be applied to repeated measures data from unbalanced designs (i.e. multiple independent variables with unbalanced multiple levels on each factor). This type of analysis can also cope with the mixture of random and fixed level effects that occur with 'real-world' data (Cnaan, Laird & Slasor, 1997). Furthermore, it can also cope with missing data and 'nested' (hierarchical models).

Logistic regression model. A data analysis technique to derive an equation to predict the probability of an event given one or more predictor variables. This model assumes that the natural logarithm of the odds for the event (the log it) is a linear sum of weighted values of the predictor variable. The weights are derived from data using the method of maximum likelihood.

Meta-analysis. A statistical method of summarizing the results from a group of similar studies.

Mobility. The ability to move independently and safely from one place to another.

Motor unit. A motor neuron and all the muscle fibres it innervates.

Multidisciplinary. Refers to more than one health care professional from different disciplines.

Multifactorial. Strategy used to describe multiple components or interventions.

Muscle endurance. Muscle's ability to contract continuously at a sub maximal level.

Muscle power. Muscle's ability to forcefully contract in a very short time.

Muscle quality. Refers to a loss of strength per unit muscle mass.

Muscle strength. The amount of strength (expressed in Newton) performed by a muscle (Howley & Franks, 1995). The capacity to perform muscle strength depends on muscle mass and innervations (neuromuscular function).

Odds ratio (OR). Odds in favour of being exposed in subjects with the target disorder divided by the odds in favour of being exposed in control subjects (without the target disorder).

Perturbation. A disturbance to a system. The disturbance may be external or internal in origin.

Physical activity. Bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level (Caspersen, Powell & Christenson, 1985). Habitual physical activity is a representation of an individual's *usual* physical activity.

Postural control. Refers to regulating the body's overall position (posture) in space with the aim of keeping balance in a resting situation (static balance) or during movement (dynamic balance) (Shumway-Cook & Woollacott, 1995). It could also be defined as the ability to keep the body's CoG on the base of support while statically standing and sitting and during movement. In short, it would be the ability to acquire, maintain, and control posture, spontaneously and as a result of external changes, and to control changes or shifts from different postures without losing postural stability. It has two aims (Amblard et al., 1985; Horak & McPherson, 1996):

- Stability: Ability to maintain the projection of the CoG within stability limits.
- Orientation: Ability to maintain an appropriate relationship of body segments, among themselves and between them and the environment, to perform a task.

Postural control for orientation and stability requires perception (integration of sensory information to analyse body position and movement in space) and action (generation of forces to adjust the different body parts, with the integration of both nervous and musculoskeletal system being necessary). These objectives can be achieved with the interaction in the CNS of all the information collected by the 3 main systems in charge of balance. An appropriate postural control depends on the integrity of these 3 systems and their complex interactions: vestibular, visual and somatosensory systems. The

CNS processes and integrates all the information given by the vestibular system, visual and somatosensory or proprioceptive information, and develops a motor and visual response with the aim of maintaining postural control and stable vision, as well as a correct position of head and body in space.

Postural stability. The ability of an individual to maintain the position of the body, or more specifically, its centre of mass, within specific boundaries of space, referred to as stability limits (Shumway-Cook & Woollacott, 1995).

Posture. Refers to the biomechanical alignment of he individual body parts as well as the orientation of the body to the environment.

Power. Refers to the product of force and velocity (power = force x velocity).

Predictive validity. A risk assessment tool would have high predictive validity if the predictions it makes of the risk of falling in a sample became true – that is it has both high sensitivity and specificity.

Prevalence. The proportion of persons with a particular disease within a given population at a given time.

Proprioception system. Collects the sense of movement, position and musculoskeletal tension. It consists of some mechanoreceptors located deep in the muscles, joints and connective tissue. Collected information is transmitted through posterior part of the spinal cord, going through the medial lemniscuses, and finally reaching the cerebral cortex, where it becomes conscious (DeMyer, 1987).

Randomised controlled trial (RCT). A clinical trial in which the treatments are randomly assigned to subjects. The random allocation eliminates bias in the assignment of treatment to patients and establishes the basis for the statistical analysis.

Reactive postural control. Actions that cannot be planned in advance due to the unexpected nature of an event.

Receiver operating characteristic (**ROC**). Or simply ROC curve, is a graphical plot of the sensitivity, or true positives, vs. (1 − specificity), or false positives, for a binary classifier system as its discrimination threshold is varied.

Relative risk (RR). An estimate of the magnitude of an association between exposure and disease, which also indicates the likelihood of developing the disease among persons who are exposed, relative to those who are not. It is defined as the ratio of incidence of disease in the exposed group, divided by the corresponding incidence in the non-exposed group.

Residential care setting. An institutional dwelling where older people have specialist health care professionals available at all times.

Sarcopenia. Refers to the age-associated loss of skeletal muscle mass.

Self-efficacy. Refers to an older person's perception of their capability. High efficacy relates to increased confidence. This term is referred to in relation to the fear of falling.

Sensitivity. Percentage of those who developed a condition who were predicted to be at risk.

Sensitivity analysis. Allows for uncertainty in economic evaluations. Uncertainty may arise from missing data, imprecise estimates or methodological controversy. Sensitivity analysis also allows for exploring the generalisability of results to other settings. The analysis is repeated using different assumptions to examine the effect on the results.

Specificity. Percentage of those correctly predicted not to be at risk.

Stability limits. The maximum distance an individual is able or willing to lean in any direction without changing the base of support. They could also be defined as the maximum angle as measured from the vertical a person can move without modifying his/her base of support (Nashner & Peters, 1990). If at some moment the CoG lies outside this stability limit, fall is unavoidable unless a correction manoeuvre is quickly performed.

Strength. The ability to change the state of movement of an object when acting upon it, and being expressed as the result of multiplying mass by acceleration (Manso, Valdivieso & Caballero, 1996)

Stride length. The distance covered from one heel strike to the next heel strike by the same foot.

Systematic review. A way of finding, assessing and using evidence from studies – usually RCT – to obtain a reliable overview.

Tailored. Refers to intervention packages or programmes that are planned to meet the needs of patients.

Targeted. Refers to those interventions that are aimed at modifying a particular risk factor.

Validity. The extent to which a variable or intervention measures what it is supposed to measure or accomplish:

> **Internal validity** – of a study refers to the integrity of the design.
> **External validity** – of a study refers to the appropriateness by which its results can be applied to non-study patients or populations.

Vestibular system. Sensory receptors needed to keep balance while standing (Bartual, 1998). It has some movement sensors that send information to the CNS, where vestibular ocular reflex (VOR) and vestibular spinal reflex (VSR) are generated, in charge of stabilizing sight and postural control, respectively.

Visual system. Sensory receptors that collect information of the relationship among the different body parts and between them and the environment and send it to our cerebral cortex to contribute to keep balance in a certain position.

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

6MWT - six minute-walk test

1RM - one repetition maximum score

ACSM - American College of Sports Medicine

ADL - Activities of Daily Living

AGS - American Geriatrics Society

AP - Anterior - Posterior

BBS - Berg Balance Scale

BI - Barthel Index

CI - Confidence Interval

cm - centimetres

CNS - Control Nervous System

CoG - Centre of Gravity

CSA - Cross Sectional Area

CTSIB - Clinical Test for the Sensory Interaction on Balance

DGI - Dynamic Gait Index

EMG - Electromyogram

FICSIT - Frailty and Injuries: Cooperative Studies of Intervention Techniques

FITNESS - Frailty Interventions Trial in Elderly Subjects

FRT - Functional Reach Test

FSQ - Functional Status Questionnaire

FSST - Four Square Step Test

GARS - Groningen Activity Restriction Scale

HI - High Intensity

HR - Heart Rate

hr - hour

IADL - Instrumental Activities of Daily Living

ICC - Intraclass Correlation Coefficient

Kcal - kilocalories

Km - kilometres

LGN - Lateral Geniculate Nuclei of the thalamus

LI - Low Intensity

LS - Leg Strength

min - minute

ML - medio-lateral

mm - millimetres

MMSE - Mini Mental Status Examination

ms - milliseconds

m/s - metres per second

MSL - Maximal Step Length

MTGUG - Modified Timed Get Up and Go

OR - Odds Ratio

POMA - Performance Oriented Mobility Assessment

POW - Power

PPT - Physical Performance Test

PPV - Positive Predictive Value

PT - Peak Torque

r - Pearson product-moment Correlation Coefficient

RCT - Randomised Controlled Trial

RFD - Rate of Force Development

rho - Spearman's rank Correlation Coefficient

ROC - Receiver Operating Characteristic (ROC curve)

RR - Relative Risk

RST - Rapid Step Time

s - seconds

SD - Standard Deviation

SLB - Single Leg Balance

SOT - Sensory Organization Test

SPPB - Short Physical Performance Battery

TGUGT - Timed Get Up and Go test

TS - Tandem Stance

TW - Tandem Walk

UK - United Kingdom

VOR - Vestibular Ocular Reflex

VSR - Vestibular Spinal Reflex

WHO - World Health Organization

wk - week

1. INTRODUCTION

Scope of research

In developed countries, the most relevant demographical characteristic of current times is the ageing of the population (Kinsella & Velkoff, 2001). In Spain, in 1960 people over 65 years old accounted for 8% of the entire population; in the last 30 years this number has steadily increased, so that in the year 2000 it was 16.9%, and, according to Eurostat predictions, it will be 17.9% in 2010 and 20.3% in 2015. Given the current number of old people and future expectations about elderly population's incidence, it is considered to be essential that health care professionals, responsible entities and organizations, with the collaboration of the elderly themselves, establish strategies that allow us to objectively assess those areas with the highest functional deficits, to offer the appropriate intervention, and thus to ensure healthy ageing and higher quality of life to the greatest number of citizens possible (Sintes & Ramón, 2003).

Decrements in lower extremity muscle strength, balance impairments and gait disorders are associated with an increased risk of functional decline, and they have been linked to physical frailty, falls, and impaired mobility in elderly people (Fried et al., 2000; Guralnik et al., 1995; Newman et al., 2006). Functional decline is an important part of health care of the elderly, because it has significant consequences for older adults in terms of morbidity, mortality, and loss of independence. Approximately one third of older people living in the community fall at least once a year, with many suffering multiple falls. Falling rates are higher in older women than in older men and continue to increase with age above 65 years (Varas-Frabra et al., 2006). The incidence is increased in people with particular physical conditions that affect posture, strength, balance and gait. Falls can also result in disability, restriction of activity and fear of falling, which can reduce quality of life and independence and contribute to an older person being admitted to a nursing home.

The maintenance of postural stability is a highly complex skill which is dependent on the coordination of a vast number of neurophysiologic and biomechanical variables. Normal ageing is associated with decreased ability to maintain postural stability during normal gait, when responding to unexpected perturbations, when avoiding obstacles, and when performing usual tasks such as standing (Shumway-Cook et al., 2007). This decrease in postural stability in older people may be mainly explained by deficits in muscle strength in the lower limb, but also by impairments in peripheral sensory systems (e.g. somatic sensation), visual acuity, vestibular function, and central processing of afferent inputs.

Primary care professionals are subject to many competing demands on their time, which results in time spent with each individual being necessarily brief. Therefore, a rapid and objective physical function assessment tool is required to assist in identifying causative factors in people at high risk of developing functional decline, thus at risk of suffering a fall. Much attention has been focused on regular physical activity as a means to enhance health and maintain function in old age, and several exercise programs have been designed to improve the parameters of fitness and, in turn, enhance function. A simple screening procedure linked with effective public health interventions may offer great scope for reducing functional decline in at-risk older people.

The PhD dissertation presented below is a compilation of three papers published in international journals, with peer review evaluation and indexed in international data bases. This compilation relates to one research topic: the study of how to assess and improve functional performance in physically frail community dwelling older adults. This dissertation will be presented as a European Doctorate, and it has been divided into three studies.

The first study assessed the reliability and sensitivity of a modified version of the 'Timed Get Up and Go' (TGUG) test in predicting fall risk, using both a quantitative and qualitative approach in individuals older than 65 years. The modified TGUG test had been developed as a physical function assessment to identify older people with impairments in one or more of the major physiological domains that have a substantial effect on the ability of older persons to remain independent: muscular weakness, and deficits in gait and balance. The second study assessed the construct validity of the modified TGUG test, determining the degree to which scores of a modified TGUG test were associated with other measures used in the literature to document age-related change in both functional performance and physiological impairment.

In the third study, we conducted a randomized clinical trial of a functional circuit training program aiming to determine the effect of a 12-week structured, intervention program on reducing physical frailty measures in a group of community-dwelling physically frail elderly individuals. The secondary aim of the study was to evaluate whether these improvements were sustained 6 months after the end of the training program.

2. LITERATURE REVIEW

2.1. The process of ageing

The scope of the following section is designed to highlight the concept of old age, and how ageing is linked to the process of decline in function of most body systems. Also, it will focus on the social representation of old age according to the different theories about behaviour in the last stage of life, and the theories that have been proposed to explain where, how, and why changes that take place in the process of ageing occur.

Advancements in medical technology, health care, nutrition, and sanitation have resulted in lower birth and mortality rates throughout the world (Kinsella & Velkoff, 2001). People are living longer, and the population aged 65 years and older is rapidly increasing. Average life expectancy at birth in most developed countries now is approximately 80 years, an average increase of about 25 to 30 years since 1900, with women living between 6 and 8 years longer on average than men (Kinsella & Velkoff, 2001). Moreover, adults over the age of 85 are the fastest growing segment of our population (McAuley, Kramer & Colcombe, 2004).

In order to understand the concept of old age, it is necessary to distinguish between biological age, functional age, and chronological age. The most common indicator used to define old age is chronological age, that is, the passage of time from birth in years. Biological age, also known as primary ageing or body's actual biological age when compared with standard biological age markers of the general population, refers to a group of processes within the body that eventually lead to loss of adaptability, disease, physical impairments, functional limitations, disability, and eventual death (Hayflick, 2000; Sintes & Ramón, 2003). Scientists believe that random damage that occurs within cells and among extra cellular molecules are responsible for many of the age-related changes that are observed in organisms (Hayflick, 2000). In addition, for organisms that reproduce sexually, including humans, each individual is genetically unique. As such, the rate of ageing also varies from individual to individual (Carnes & Olshansky, 2001). Despite intensive study, scientists have not been able to discover reliable measures of the processes that contribute to ageing (Hayflick, 2000). Functional age can be defined as state of health in comparison with other people of the same age and gender.

Impairments in physical fitness parameters (e.g., aerobic endurance, musculoskeletal integrity, flexibility, body composition, and the sensorimotor system) have a direct impact on a person's functional abilities (e.g., walking, stair climbing, rising from a chair), and functional limitations eventually lead to physical disabilities (Jones & Rose, 2005). Spirduso (1995) hierarchically divided physical function into five levels: physically elite, physically fit, physically independent, physically frail, and physically dependent.

As people age, they become increasingly more diverse in medical, psychological, and physical status. Differentiating between usual (or normal), pathological (or abnormal), and successful ageing is another way of categorizing the way people age (Jones & Rose, 2005). Usual ageing refers to the way most people age and is characterised by a gradual decline in body function, leading to physical impairments, disease, functional limitations, and eventually the onset of disability and death. Pathological ageing generally refers to the way individuals age who are genetically predisposed to certain diseases or have high-risk negative lifestyles that lead to premature disability and death. Successful ageing, on the other hand, is more difficult to define because the term *success* itself is quite ambiguous. Successful ageing is a qualitative description of ageing rather than one that refers to longevity or survival. Rowe & Kahn (1997) referred to successful agers as people with better than average physiological and psychosocial characteristics in late life. Successful agers are also more satisfied with life in general (Jones & Rose, 2005; Rowe & Kahn, 1997).

Bentov et al. (1993), distinguished between “ageing” and “growing old.” While ageing includes all the biological changes that develop in time, growing old refers to a social image that an elderly person produces related to the biological process of ageing. From another perspective, according to Salleras et al. (2001), ageing is both the increase in the number of old people and their weight burden on the population as a whole. In absolute terms, the concept of ageing refers to all the people at the age of 65 or over, a limit based on economic criteria, as in many countries this moment sets the dividing line between active life and retirement (Grimley & Franklin, 1992; Salleras et al., 2001; World Health Organization [WHO], 1995). Ham & Sloane (1995) defined ageing as an extraordinarily gender-specific process from the demographic point of view. The justification for this phenomenon is probably due to genetic, behavioural, and social stress factors that discriminate between the ageing process in males and females. Demographic ageing is considered to be a structural phenomenon with complex demographic, economic, and social implications, taking into account that a population ages when the proportion of old people increases over time.

The process of vulnerability and decline is inextricably linked to the ageing process (Fried et al., 2004; Rockwood, 2005). Studies have shown that some degree of functional loss is inevitable in very old age (Deiana et al., 1999). For instance, almost all one hundred years of age individuals have at least some functional deficits. None of the 138 centenarians evaluated in the Sardinia Study of Extreme Longevity (AKEntAnnus) had the maximum possible score on a standard performance test of lower extremity function (Deiana et al., 1999).

Ageing shows at two levels: internal and external. Internally, it is determined by the morphological and physiological wear of organs and systems. Old people have a lower capacity to cope with diseases and also adapt to environmental changes; they get tired more easily, are slower, and have less mobility and agility; they have a decrease in their perceptive skills, their mental agility, and their memory. All these factors condition their functional capacity (Fries, 1990; Soler, 2003). Functional capacity is a concept that reflects an older adult's ability to perform physical activities of daily life with relative ease (Rikli & Jones, 1999). This concept accounts for traditional physical fitness parameters such as muscle strength, cardio respiratory endurance, and flexibility, but it also includes balance. Even in healthy adults, each component of functional capacity declines with advancing age, negatively affecting quality of life (Donato et al., 2003). Preparing for old age involves investing in long-term health (Everett, Kinser & Ramsey, 2007). Social and cultural values from the environment also have a direct effect on the process of ageing. Therefore, the consequences of ageing are different for every person.

How and from what moment a person ages depends on such aspects as lifestyle, personal history, capacity of adaptation and response to organic and environmental demands (Lord, Sherrington & Menz, 2001; Soler, 2003). Heredity has a crucial role in the emergence of diseases and disabilities, but preventive behaviours and habits and attitudes throughout the lifespan (particularly in old age) are the most determining factors for successful ageing (Soler, 2003). Trost et al. (2002) noted the effects of: (a) demographic and biologic characteristics; (b) psychological, cognitive, and emotional influences; (c) behavioural attributes and skills; (d) sociocultural influences; and (e) characteristics of the physical environment, as determinants for successful ageing. There are, thus, no common patterns guiding the process of ageing. The chronological age gives us no relevant information about how an individual grows old. The image between older people is very different from one another, both in physical appearance and in their capacity of action and relationship.

The social representation of old age is explained by the different theories about behaviour in the last stage of life. As Rodríguez (1994) stated, all theories are based on the study of both, individuals and society. With regard to individuals, these theories focus on their physical and psychological state, their state of mind, their social and economic status, and their interpersonal relationships. With regard to society, they focus on cultural, social, economic, historical, and ideological contexts.

Traditionally, ageing was defined as a biological and psychological decline due to degenerative processes and reduction of some functions (*models of wear-and-tear theory*). Handler (1960) observed that ageing was the deterioration of a mature organism, as a result of essentially irreversible, time-related changes, intrinsic to all the members of the species. Ageing involved, thus, the emergence of losses and dysfunctions, the decline in the capacities, and the deterioration of health. Therefore, it involved fewer physical and psychological adaptive resources, decrease in control, and lower personal and life perspective (Reig-Ferrer, 2000). Other research lines consider that although the evidence does indicate a decline due to degenerative processes, the ageing process goes together with the development of those functions that cannot undergo regression at any moment of life such as the cognitive ability, with increases, gains, and improvements of some functions (*models of competence theory*). In this case, Birren & Renner (1977) found that the elderly population could integrate a wide range of experiences, unique sensations, structural forces, values, cultural pathways, and knowledge of an entire life span to construct a current and viable identity.

Despite the differences between these two approaches, all the theories about ageing agree that it is a process that takes place in the different systems or structures of our organism and personality, from the immune and survival-oriented biological systems to the adaptive behavioural system in response to threats and new stimuli (Fierro, 1994). Given the complexity of changes that take place in the process of ageing, many theories have been proposed to explain where, how, and why these changes take place.

As well as integrating biological and psychosocial pathways, a life course approach essentially requires some understanding of the natural history and physiological trajectory of normal biological systems. For many continuous physiological measures (e.g. muscle strength, cognitive function), different periods across the life course influence phases of biological development, stability or decline. Disease aetiology is important for understanding how exposures may differentially act in critical and/or sensitive periods. The *critical period model* is when an exposure acting during a specific period has lasting or lifelong effects on the structure or function of organs, tissues and body systems which are not modified in any way by later experience. This is also known as *biological programming* or it is sometimes referred to as a *latency model* (Hertzman et al., 2001). For example, evidence suggests that poor growth *in utero* leads to a variety of chronic disorders such as cardiovascular disease, non-insulin dependent diabetes, and hypertension. Exposures acting in later life may still influence disease risk in a simple additive way but it is argued that fetal exposures permanently alter anatomical structures and a variety of metabolic systems (Hertzman et al., 2001).

The idea that childhood is important for adult health is not new in epidemiology or public health, but was the prevailing model of health in the first half of the 20th century (Kuh & Davey Smith, 1993). The most dominant model of human development has been the idea that the first few years of life necessarily have crucial effects upon later development and adult characteristics (Ben-Shlomo & Kuh, 2002). The dominant theories of development at the beginning of the 20th century saw development as an equal and invariant sequence of developmental stages, where change was cumulative and usually irreversible. The role of the environment was to provide the initial stimuli and appropriate opportunities for growth and maturation to unfold. Environmental insults or lack of appropriate stimuli during critical periods at the embryonic stage, or during infancy, or during childhood more generally, could have long-term effects on physical or intellectual development (Brim & Kagan, 1980). Once maturity was reached, systems were less able to be manipulated.

From the late 1960s, this early life paradigm was increasingly questioned (Brim & Kagan, 1980). It was suggested that continuity of the environment, rather than early experiences *per se* lay behind evidence of long-term effects on adult characteristics (Cairns & Hood, 1983). Evidence for irreversible biological changes during critical periods of growth was stronger. Partly as a response to this controversy, a life span perspective in developmental psychology emerged in the 1970s (Cairns & Hood, 1983), where psychological development was seen as a lifelong process. The consequences of early developmental experiences could be transformed again and again by later experiences, and the course of development remained malleable into old age, in contrast to the previous paradigm which stated that once maturity was reached, systems were less able to be manipulated. In the United Kingdom (UK), Rutter (1989) argued that ‘simplistic concepts of immutable effects need to be put aside and replaced by more dynamic notions of the continuing interplay over time (...)’ but acknowledged substantial continuities between early experiences and adult psychosocial functioning. Chain reactions provide an explanation for these continuities, whereby one bad thing leads to another, or, conversely, a good experience makes it more likely that another one will be encountered (Rutter, 1989).

Demography and sociologists have investigated how the individual's life course is shaped by institutions and culture, historical and social change, and changes in individual ageing processes (such as the increase in life expectancy). At the population level, cohort effects occur because people of different ages and those who occupy different roles are differentially exposed to and influenced by particular social and economic changes. The life course perspective in sociology has encouraged life span psychologists to consider how the individual life course is embedded in the sociohistorical and bio cultural context. Changing individuals should be studied in a changing world. The emerging life course perspective in human biology, linking development to ageing, has focused on the ways in which early environmental factors can have influences on human form and function across the life span (Finch & Kirkwood, 2000).

In conclusion, according to Fries (1990), three factors contribute to the wide diversification that affects the ageing process: (a) the way every person organizes their lifespan according to their historical and cultural circumstances; (b) the incidence of different pathologies during ageing; and (c) the interaction between genetic and environmental factors.

2.2 Frailty

The scope of the following section is delimited to the concept of frailty and to expose the different definitions of frailty that have arisen in the past years.

Frailty is a term in common use among health care professionals. It is often used to label the condition of an older person who has health problems, has lost functional abilities and is likely to deteriorate further (Fairhall et al., 2008). Frailty is a state of high vulnerability, considered to be highly prevalent with increasing age (Fried et al., 2004; Fried et al., 2001; Speechley & Tinetti, 1991). It is a dynamic process that comprises a collection of biomedical factors which influences an individual’s physiological state in a way that reduces his or her capacity to withstand environmental stresses, thus increasing the risk for falls (Gill et al., 2006). Frail persons are considered to be the group of patients that presents the most complex and challenging problems to the physician and all health care professionals.

In a United States community dwelling population, aged over 65 years, Fried et al. (2001) found that 7% of the population met the criteria for frailty. Prevalence of frailty increased with each five-year cohort, and was double in women compared to men. After analysis of data from 2762 older people, Fried et al. (2001) described three separate aspects of functioning: frailty, disability and co-morbidity. Out of the people who were frail, 73% concurrently experienced one or both of the other conditions.

Researchers had shown an increasing interest in frailty because of its high prevalence. Potential definitions of frailty abound, defining frailty as synonymous with disability (Rockwood et al., 1999; Winograd et al., 1991), co morbidity (Winograd et al., 1991), or advanced old age (Deiana et al., 1999; Winograd, 1991). In fact, frailty, co morbidity and disability, are often used interchangeably to identify the physically vulnerable subset of older adults requiring enhanced care. However, recent research supports geriatricians' perceptions that these are distinct clinical entities, although interrelated, and that clinical management of each of these has its own unique content and challenges. Frailty is not synonymous with disability as many disabled people are not frail. However, frailty results in disability, and it usually indicates a person at increased risk of morbidity and mortality (Ensrud et al., 2008). At one end, frailty is interpreted as accelerated ageing; at the other, frailty is conceptualized as an entity with its own distinct pathophysiology.

The term "frail elderly" has been a Medline Medical Subject Heading term since 1991 and is defined as older adults or aged individuals who are lacking in general strength and are unusually susceptible to disease or to other infirmity. In the past ten years some researchers had tried to establish a clinical consensus of frailty (see table 2.2.1). As Rockwood (2005) postulated, for the concept of frailty to be of practical utility, its theoretical conceptualization should be translatable into an operational definition. Bayles (1997) defined a frail adult as weak and extremely vulnerable.

More recent research defined frailty as a clinical syndrome in which three or more of the psycho physiological criteria shown in table 2.2.1 were present (Fried et al., 2001). Rockwood et al. (2005) described the concept of frailty as a multidimensional syndrome of loss of reserves that gives rise to vulnerability. There is also a strong rationale for the inclusion of additional components such as cognition and mood (e.g.

apathy) (Bergman et al., 2007), although the trajectory of frailty that begins with cognitive decline may differ from the trajectory that begins with physical components. Depression was not included as one of the five characteristics in the model of frailty mentioned above, but items from a depression scale were used to measure one of the characteristics: self-reported exhaustion (Fried et al., 2001). Bortz's frailty definition (2002) and the definition of frailty used in the Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT) trials were focused on strength, mobility, balance and endurance (Bortz, 2002; Ory et al., 1993). Moreover, in focus groups, older patients and their caregivers emphasized emotional and social domains of frailty, in addition to the physical ones (Studenski et al., 2004). Clinical consensus of frailty has been reported by later reviews to include wasting (both loss of muscle mass and strength, and weight loss), loss of endurance, decreased balance and mobility, slowed performance and relative inactivity, and, potentially, decreases in cognitive function (Bergman et al., 2007; Ferrucci et al., 2004; Fried et al., 2004). Nevertheless, despite the attempt to report a clinical consensus, conflicting ideas abound on the definition of frailty and what criteria should be used for its recognition.

Health outcomes due to frailty contribute to an increased demand for medical and social care, and are associated with increased economic costs. As demographic trends indicate a rise in the older population, this healthcare burden will increase (Bergman et al., 2007; Gill et al., 2006).

Table 2.2.1

Summary of frailty definitional information

Definitional information	**Authors**	**Year**
Frail elderly is defined as older adults or aged individuals who are lacking in general strength and are unusually susceptible to disease or to other infirmity.	Medline Medical Subject Heading	1991
A frail adult should be: - Weak - Vulnerable - Slight And should have one or more of the following: - Extreme old age - Some type of disability - Presence of multiple chronic diseases - Presence of geriatric syndromes	Bayles	1997

Definitional information	Authors	Year
Frailty is a clinical syndrome in which three or more of the following criteria are present: - Unintentional weight loss (10lbs in the past year) - Self-reported exhaustion - Weakness - Slow walking speed - Low physical activity	Fried et al.	2001
Frailty is the result of early disease in multiple systems resulting in impaired muscle strength, mobility, balance, and endurance.	Bortz	2002
Frailty differs from disability and cited the following as features of frailty: - Under nutrition - Dependence - Prolonged bed rest - Pressure ulcers - Gait disorders - Generalized weakness - Extreme old age - Weight loss - Anorexia - Fear of falling - Dementia - Hip fracture - Delirium - Confusion - Going outdoors infrequently - Polypharmacy	Fried et al.	2004
In focus groups, older patients and their caregivers emphasized emotional and social domains of frailty, in addition to the physical ones.	Studenski et al.	2004
Frailty is a multidimensional syndrome of loss of reserves such as energy, physical ability, cognition and health that gives rise to vulnerability.	Rockwood et al.	2005
Clinical consensus of frailty: - Wasting (both loss of muscle mass and strength, and weight mass) - Loss of endurance - Decreased balance and mobility - Slowed performance - Relative inactivity - Decreases in cognitive function	Bergman et al.	2007

2.3 Falls in the elderly

The scope of the following section is restricted to the following areas: definition of the concept of fall, incidence of falls and associated outcomes, and risk factors for falls.

2.3.1 Definition of fall

In 1987, the *Kellogg International Working Group on the Prevention of Falls in the Elderly* defined a fall as "unintentionally coming to the ground or some lower level and other than as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure" (Gibson et al., 1987). Since then, many researchers have used this or very similar definitions of a fall. This definition is appropriate for studies aimed at identifying factors that impair sensorimotor function and balance control, whereas the broader definition (which includes dizziness and syncope in the concept of fall) is appropriate for studies that also address other causes of falls such as postural hypotension and transient ischemic attacks (Lord et al., 2001).

On the contrary, according to Exton-Smith, Smith & Weksler (1988), a fall is the result of carelessly performing activities such as long and quick movements, which the person used to be able to perform but now surpass the capacity of the individual's self-adjustment mechanisms. The FICSIT trials define a fall as unintentionally coming to the ground or some lower level. Coming to rest against furniture, a wall or any other structure is not considered a fall (Buchner et al., 1993). More recently, Reuben et al. (2002) defined a fall as any disturbance of balance during routine activities that resulted in an unintentionally coming to rest on the ground or lower level with or without loss of consciousness. This definition is similar to the Kellog's International Working Group definition (Gibson et al., 1987). It is also important to distinguish between an injurious and a non-injurious fall, depending on the injuries due to the fall such as bruises, cuts or grazes, broken wrist, hip, and/or ribs, back pain, among others. An injurious fall refers to a fall resulting in a fracture or soft tissue damage that requires treatment. Whether a fall requires hospitalization or not should also be registered (Lord et al., 2001).

2.3.2 Incidence of falls and associated outcomes

Falls and fall-related injuries among older people are major issues for health and social care providers in Europe and indeed the world, because of the rapid increases in life expectancy observed during the twentieth century. Falls are among the most common and serious problems facing elderly persons, are the leading cause of injury-related hospitalization in persons aged 65 years and over, and account for 4% of all hospital admissions in this age group (Baker & Harvey, 1985; Cryer, 2001). Approximately 5% of older people in community-dwelling settings who fall in a given year experience a fracture or require hospitalisation (Rubenstein et al., 2000; Tinetti, Speechley & Ginter, 1988). They are also a major reason for admission to a residential care setting, even when no serious injury has occurred (Tinetti, 2003). Falling is associated with increased mortality, morbidity, reduced functioning, loss of independence and premature hospital and geriatric admissions (Brown, 1999; Ciccarelli, 2003; Kannus et al., 2005; Perell et al., 2001). Moreover, falls are the most common cause of accident amongst persons over 65, representing the main cause of death by injury (Abrams & Berkow, 1990). Both the incidence of falls and the complications associated with falls increase considerably after the age of 60. An estimated 25 to 35% of adults aged 65 years and older fall each year (Boulgarides et al., 2003; Royal College of Nursing, 2004; Tinetti, 2003). After the age of 75 years, the rates are higher (American Geriatrics Society [AGS] et al., 2001).

Data about incidence of falls vary depending on the age of patients (Campbell et al., 1990; Tibbits, 1996), gender, frailty, location (family or institutional environment), and degree of activity (Vellas et al., 1996). Women fall more often than men until the age of 75 due to increased impairment in mobility among women and to a higher number of associated risk factors. After the age of 75, the frequency is similar for both (Ribera-Casado & Cruz-Jentoft, 1991) consistent with the higher mortality rates among men. In 1977, Exton-Smith examined the incidence of falls in 963 65-year-old people. He found that in women the proportion of falls increased by 30% in the 65-69 age group and more than 50% in those over the age of 85. In men, the proportion of falls increased 13% in the 65-69 age group and to levels of approximately 30% in those aged 80 and over. Studies undertaken since Exton-Smith's work (1977) have reported similar findings demonstrating that the incidence of falls increases with age (Campbell, Borrie & Spears, 1989; Tinetti et al., 1988). As stated previously, the process of vulnerability and decline is inextricably linked to the ageing process (Fried et al., 2004; Rockwood, 2005).

More recent prospective studies in community settings have reported a slightly higher incidence of falls. Thus, in a study with 761 people older than 70 years carried out in New Zealand, Campbell et al. (1989) found that 40% of 465 women and 28% of 296 men had fallen at least once during the period of a year, with a total incidence of 35%. In another study about falls and fractures in Randwick (Australia), findings were that 39% of 341 women reported one or more falls during the period of a year (Lord et al., 1993). Several factors could account for the increased falling rates in more recent studies; in previous studies, some falls might not have been adequately documented, as most studies relied upon self-reporting information once a month. More contemporary studies use more frequent follow-up assessments such as home visits once a week, telephone calls, or diaries. In the twentieth century, there is a higher life expectancy, and a greater percentage of the elderly population. Thus, there are more people prone to fall, because advanced age is an important risk factor for falls (Tinetti, 2003).

In a study by Varas-Fabra et al. (2006) carried out in three primary healthcare centres in Córdoba, Spain, with 362 community-dwelling people over 70 years old, the prevalence of falls was 31.8%. 12.9% of subjects reported more than one fall during the previous year. 55.3% of falls took place at home. 71.8% of subjects had physical injuries, with 7.8% of fractures. 44.7% reported that they were afraid of a new fall, and 22% limited their mobility after their fall. 3% contacted the health care system, and 3.3% had to be admitted to hospital (Varas-Fabra et al., 2006). The most common risk factors for falls identified in this study were advanced age, being a women, being widowed, with only primary studies, reporting the lowest perceived health status, and taking more than four drugs.

Incidence rates for falls in nursing homes and hospitals are two or three times greater than in the community, and complication rates are also considerable higher. Ten to 25% of institutional falls result in fracture, laceration, or need for hospital care (Rubenstein et al., 2000). For example, Luukinen et al. (1994) found that the incidence of falls in people older than 70 living in an old people’s home was three times that of people living independently at their homes, mainly due to being older, having a lower degree of activity, and having greater physical impairments.

2.3.3 Risk factors for falls

To identify those at risk of falling, it is necessary to review the evidence base for risk factors, looking at older people in both community dwelling and residential care settings. The following chapter sought to answer what are the key risk factors that should be used to identify those at highest risk of a first or subsequent fall, thus with a higher probability of becoming frail and functionally dependent.

Falls are rarely true accidents and the epidemiology of their incidence does not adhere to that of purely random events (Morris, 2007). The aetiology of falls amongst senior citizens is generally considered multi-factorial, with more than 400 separate risk factors described (Oliver, Hopper & Seed, 2000), and covering intrinsic and extrinsic circumstances (Gillespie et al., 2003). Intrinsic risk factors are due to age- or disease-related changes occurring within the older adult; extrinsic risk factors are due to factors that are external in nature, such as the presence of environmental hazards in the home or community that elevate the risk for falls during routine activities associated with daily living.

The Perell et al. (2001) review provided information on the assessment of older people at risk, and empirical evidence relating to risk factors predictive of falling. This review reported the mean relative risk (RR) or odds ratio (OR) and rank for each factor. However, no details were given of the study design of the included studies. The Perell et al. (2001) review was written following the AGS et al. (2001) guidelines. Table 2.3.1 gives ranked summaries of data on the strength of association of risk factors for falls identified in large epidemiological studies.

Table 2.3.1

Univariate summary of the most common intrinsic risk factors for falls (Perell et al., 2001)

Risk factor	Mean RR/OR (Range)
Muscle weakness	4.4 (1.5-10.3)
History of falls	3.0 (1.7-7.0)
Gait deficit	2.9 (1.3-5.6)
Balance deficit	2.9 (1.6-5.4)
Use assist devices	2.6 (1.2-4.6)

Risk factor	Mean RR/OR (Range)
Visual deficit	2.5 (1.6-3.5)
Arthritis	2.4 (1.9-2.9)
Impaired activities of daily living	2.3 (1.5-3.1)
Depression	2.2 (1.7-2.5)
Cognition impairment	1.8 (1.0-2.3)
Age over 80 years	1.7 (1.1-2.5)

In 2004, the Royal College of Nursing published an evidence review of risk factors for falls which included 28 studies (out of 1396 previously selected), giving preference to systematic reviews and prospective cohort studies of risk factors of falls in older people. Table 2.3.2 shows the frequency that the risk factor was reported in the included studies.

Table 2.3.2

Frequency of reporting of risk factor in included studies (Royal College of Nursing, 2004)

Risk factor	Frequency reported
Falls history	11
Mobility impairment	8
Visual impairment	5
Balance deficit	5
Gait deficit	4
Mental status	4
Functional dependence	4
Fear	3
Low body mass	3
Depression	3
Diabetes	2
Environmental hazards	2
Incontinence	2
Multiple medications	Meta-analysis: n=14 studies

Risk factor	Frequency reported
Psychotropic drugs	Meta-analysis: n=11 studies
Anti-arrhythmic	Meta-analysis: n=10 studies

Within home-dwelling populations, subtle differences in their risk profile can be identified, which also provide intuitive evidence of variation in underlying frailty (Morris, 2007). Falls occur indoors more commonly than outside. In one study, indoor falls were found to be associated with slower walking speeds, cognitive impairment, multiple co-morbidities, age above 75 years and poor performance in tests of physical function. Outdoor falls were found to be associated with slower gait speed, visual impairment, depression, lower stepping capability and age below 75 years (Bergland, Jarnlo & Laake, 2003). The authors of that study suggested that outside falls are linked to compromised health status in more active individuals. It has also been shown that, although less frequent than falls indoors, where falls occur in the more hazardous and challenging environment outside of the home, they are more likely to result in significant injury (Speechley & Tinetti, 1991). Thus, there is some discernible variation in the risk factor profiles for different types of fall.

The way in which fallers are classified also influences the pattern of associated risk factors. Lord et al. (1994) showed that the physiological parameters of visual contrast sensitivity, reaction time, body sway, quadriceps strength and vibration were similar in non-fallers and once-only fallers, but these measures were significantly worse in recurrent (twice or more) fallers. This suggests that people who fall only once are characteristically more closely related to non-fallers than to those who fall twice or more in a defined time period.

According to Tinetti (2003), each of the risk factors stated below had demonstrated to increase the risk of falling in at least two observational studies: arthritis, depression symptoms, cognitive, visual, and balance impairment, gait disorders, lower-limb muscle weakness, and polypharmacie (more than 4 medications). Melzer, Benjuya & Kaplanski (2004) added advanced age, chronic diseases, and previous history of falls as the most likely intrinsic risk factors to cause a fall.

According to Perell et al. (2001) (shown in table 2.3.1) and the Royal College of Nursing review (2004) (shown in table 2.3.2), muscle weakness, balance impairment and gait deficit are the most important intrinsic and physiological risk factors for falling in the elderly, all of which diminish functional independence and are modifiable. Decrements in lower extremity muscle strength, balance impairments and gait disorders are associated with an increased risk of functional decline (Campbell et al., 1989; Daubney & Culham, 1999; Guralnik et al., 1995; Heitmann et al., 1989; Lord et al., 2001; Tinetti et al., 1988; Wolfson et al., 1995), and it has been linked to physical frailty, falls, and impaired mobility in elderly people. Functional decline is an important part of health care of the elderly, because it has important consequences for older adults in terms of morbidity, mortality, and loss of independence.

In the subsequent chapters we have attempted to evaluate the evidence for each of the three physiological risk factors implicated with functional decline.

2.4 Muscle weakness

Muscle weakness is consistently reported as an independent risk factor for high mortality in older adults (Newman et al., 2006). Muscle strength is relatively well maintained up until the age of 50. Thereafter, there is a significant decline such that the muscle strength of people in their 80s is about 40% less than that of young adults (Doherty, Vanervoort & Brown, 1993). Muscle weakness has important consequences in older people; lower limb muscle weakness, in particular, is reflected in reduced general mobility and difficulty in undertaking transfers such as rising from a chair (Guralnik et al., 1995).

The ageing process is characterized by muscle fibre atrophy and reduction in skeletal muscle mass (sarcopenia) (Brooks & Faulkner, 1994; Goodpaster et al., 2001; Katsiaras et al., 2005). Sarcopenia is related to functional impairment (Visser et al., 2002), disability (Rantanen, 2003), falls (Lord et al., 1994), and loss of independence (Rantanen et al., 2002) in older adults. Maximal contractile muscle strength and power are also markedly reduced with ageing, which is generally associated with muscle weakness (Aagard et al., 2007; Brooks & Faulkner, 1994; Goodpaster et al., 2001; Katsiaras et al., 2005; Krivickas et al., 2001; Skelton et al., 1994).

Cross-sectional studies suggest that the sarcopenia phenomenon starts toward the end of the fifth decade of life (Janssen et al., 2000), which also corresponds with the onset of strength decline (Katsiaras et al., 2005). This loss of muscle mass is greater for the muscles of the lower limbs than for the upper limbs, and from 20 to 70 years of age, lower limb muscle mass decreases by ~25% (Janssen et al., 2000). Recently, however, several longitudinal studies reported that the decline of strength was ~60% greater than estimates from cross-sectional comparisons, and that the age-associated changes in muscle mass explained ~5% of the variance in the change in strength (Hughes et al., 2001). These results have recently been replicated with a 3-year longitudinal study, where although leg muscle mass was significantly correlated with leg strength, the changes did not track each other and maintaining or actually gaining lean mass did not prevent the age-associated loss in strength (Goodpaster et al., 2006). Frontera et al. (2000) reported that muscle strength at baseline and changes in muscle cross- sectional area (CSA) were independently correlated with strength decline over 12 years. Taken together, these studies suggest that preserving lean mass would indeed help attenuate the strength decline with age, and that alteration in muscle quality play a role in the loss of strength in old age. Thus, muscle strength rather than muscle mass should be used as an intermediate endpoint in interventions designed to improve functional or physical capacity.

The Baltimore Longitudinal Study on Aging (Metter et al., 1999) reported that men had greater rates of strength decline than women, and that increasing age was associated with greater loss of strength. When the cross-sectional area (CSA) rather than muscle mass (or volume) of essential muscles of locomotion is considered, a 25-33% difference in quadriceps CSA is found between young (20-29 years) and elderly (70-81 years) adults (Lexell, Taylor & Sjostrom, 1988). It must be noted that fat accumulation occurs in skeletal muscles as we grow old and there could be uncoupling of muscle cross sectional area and muscle fibre strength with ageing, so that lean body mass might not reflect the effective muscle strength in old age (Morley et al., 2001). Maintenance or even gain of lean mass in older men and women did not necessarily prevent the loss of strength in a previous study (Goodpaster et al., 2006). Thus, while these data did not diminish the importance of maintaining muscle mass with old age, they did underscore the importance of muscle quality (in addition to muscle quantity) in older adults (Goodpaster et al., 2006).

An even greater understanding of the disassociation between muscle mass and strength can be garnered from the examination of the changes in strength associated with increased (i.e., resistance exercise training) and decreased physical activity levels. The principle argument here is that increased strength observed during the early phases of resistance training occurs before the exercise stimulus is actually capable of eliciting gross morphological changes in muscle, as evidence by increases in maximal voluntary force occurring before changes are observed in electrically stimulated maximal force (Gabriel, Kamen & Frost, 2006). This suggests that short-term gains in strength are not related to factors associated with the intrinsic capacity of the muscle itself. These factors constitute a complex interaction between changes in activation and discharge properties of motor units as well as the adaptation in the central command for learning.

Increased age is also associated with a deterioration of the muscle elastic behaviour (Bosco & Komi, 1980). Bosco & Komi (1980) investigated age dependence of the mechanical behaviour of the leg extensor muscle using vertical jumps with and without a stretch-shortening cycle on the force-platform in a total of 226 subjects (113 females and 113 males) ranging in age from 4-73 years. The results suggested that it was not only the performance of pure concentric contraction that was influenced by the maturation and ageing processes but, that the elastic behaviour of the muscle was also affected by the same processes. With ageing humans, the muscle fascicle length and pennation angle reportedly decrease (Narici et al., 2003), and the tendon compliance increases (Karamanidis & Arampatzis, 2005). These changes may influence the strength and power production not only in static but also in dynamic movements. Although it is not known in detail whether the muscle activation pattern in agonist muscles shows age-specific modifications, the measurements of antagonist co activation have shown increased level of co activation in elderly individuals (Seidler, Alberts & Stelmach, 2002).

For the sedentary elderly individual, the loss in muscle strength may represent a serious risk for loss of independence. This reduction in muscle function may lead to an impaired ability to perform chair rises and stair and level walking (Guralnik et al., 1995; Tinetti et al., 1988) while also reducing the capacity to counteract unexpected perturbations in body posture and postural balance; potentially increasing the risk for falls (Aagard et al., 2007; Guralnik et al., 1995; Heitmann et al., 1989; Skelton et al., 1994; Tinetti et al., 1988). A sit-to-stand movement requires muscle strength greater than other daily activities, such as walking or stair climbing (Ploutz-Snyder et al., 2002). Similarly, Lord et al., (2002) demonstrated that in community-dwelling older people, despite the fact that sit-to-stand performance was influenced by multiple physiological processes, quadriceps strength had the highest beta weight, indicating it was the most important variable in explaining the variability in sit-to-stand times (Lord et al., 2002).

Furthermore, leg muscle strength is positively related to mobility (Aagard et al., 2007; Brooks & Faulkner, 1994; Goodpaster et al., 2001; Krivickas et al., 2001), and inversely related to the incidence of hip fractures (Aniansson et al., 1983; Aniansson et al., 1984). While ageing is accompanied by a gradual deterioration in muscle function, the capacity for rapid muscle force exertion (contractile rate of force development, RFD) is particularly compromised (Aagard et al., 2007). In functional terms, RFD is a highly important mechanical muscle parameter because rapid movements typically involve muscle contractions within 50-200 ms, which is considerably less than the time it takes to reach peak muscle force (approximately 350 ms) (Aagard et al. 2002). Hence, a fast RFD plays an important role for the ability to perform rapid and forceful movements in elderly individuals who need to control unexpected perturbations in postural balance.

In prospective community studies, reduced knee extension strength was found to increase the risk of both falls and fractures (Lord et al., 1994; Nguyen et al., 1993). Other studies have reported that in addition to reduced quadriceps strength, decreased ankle dorsiflexion (Whipple, Wolfson & Amerman, 1987) and reduced hip flexor strength (Robbins et al., 1989) also increase the risk of falls in older people. Whipple et al., (1987) compared the strength of the knees and ankles of a group of nursing home residents with a history of falls with age-matched controls. Peak torque (PT) and power (POW) were recorded at two limb velocities (60 degrees/s and 120 degrees/s) on a Cybex II Isokinetic dynamometer for four muscle groups: knee extensors, knee flexors, ankle plantar flexors and ankle dorsiflexors. The PT and POW of fallers were significantly decreased for all four muscle groups in comparison to controls, with the ankles showing the greatest decrements. Although POW in fallers was significantly lower at the higher velocity in both joints, the decrease was most prominent in the ankles. Dorsiflexion POW production in fallers was the most affected of all the motions (7.5 times less than the control value).

In another study, Tinetti et al. (1995a) assessed the physical performance and functional dependence of 927 community-dwelling people aged 72 years and over; the highest RR (95% CI) was found in strength impairments [2.2 (1.5-3.2)] and functional dependence [2.0 (1.3-3.1)], below cognitive impairments [2.6 (1.7-4.0)]. In conclusion, any lower extremity disability such as loss of strength is associated with increased risk of falling (Campbell et al., 1989; Skelton, Kennedy & Rutherford, 2001; Tinetti et al., 1988; Tinetti et al., 1995a). It may be that the decline in strength results in physical functioning dropping below the threshold where activities of daily living become difficult and then impossible to carry out. When strength, endurance, muscle power, and hence function declines sufficiently, one is unable to prevent a slip, trip or stumble becoming a fall.

2.5 Balance impairment

The peripheral sensory systems that are responsible for maintaining posture control also deteriorate with ageing (Daubney & Culham, 1999; Fried et al., 2000; Tinetti et al., 1988), and the ability to maintain control of posture is important for the successful performance of most daily activities (Daubney & Culham, 1999).

People normally maintain control of posture by integrating vestibular, visual and somatosensory information from the central nervous system. Therefore, when the above-stated organ systems are impaired, dizziness and body sway appear. The peripheral sensory systems that are responsible for maintaining posture control deteriorate with ageing (Aniansson et al., 1984; Daubney & Culham, 1999; Fried et al., 2000; Guralnik et al., 1995; Heitmann et al., 1989; Iezzoni et al., 2000; Lord et al., 2001; Lord et al., 1994; Maki, Holliday & Topper, 1994; Tinetti et al., 1988; Wolfson et al., 1995), and the ability to maintain control of posture is important for the successful performance of most daily activities (Daubney & Culham, 1999). Deterioration in postural stability may be a major contributor to many falls, resulting in an impaired ability to correct for the many postural disturbances in daily life (Daubney & Culham, 1999; Maki et al., 1994).

It has been suggested that a decrease in the ability to generate force in the lower-extremity muscles contributes to balance impairment, although the relationship between impairments in muscle force generation and balance have not been extensively investigated (Daubney & Culham, 1999; Iverson et al., 1990; Wolfson et al., 1995). Wolfson et al. (1995), found that torques generated by the ankle muscles were reduced in older adults who were identified as having the greatest balance impairment on the Sensory Organization Test (SOT). Iverson et al. (1990), reported a relationship between hip muscle force and single-limb stance time and between hip muscle force and sharpened Romberg test scores. Ageing may also lead to impaired balance with a decrease in event detection and speed of postural adjustments

(Aagaard et al., 2007). The decreased ability to develop force rapidly in older people seems to be associated with a lower capacity for neuromuscular response in controlling postural sway (Aagaard et al., 2007; Daubney & Culham, 1999).

Normal relaxed standing is characterized by small amounts of postural sway, which has been defined as the constant small deviations from the vertical and their subsequent correction to which all human beings are subject when standing upright (Sheldon, 1963). The control of postural sway when standing involves continual muscle activity (primarily of the gastrocnemious muscles) and requires an integrated reflex response to visual, vestibular and somatosensory inputs (Fitzpatrick, Rogers & McClosky, 1994). The stability limit of normal relaxed standing is the area bounded by the two feet on the ground, whereas the stability limit of unipedal stance is reduced to the area covered by the single foot in contact with the ground. Due to this reduction in the size of the stability limit, unipedal stance is an inherently more challenging task requiring greater postural control.

The generalized decline in sensory functions due to normal ageing and its contribution to increased postural sway have been widely evaluated in the literature. Several studies have reported age- associated increases in standing postural sway after the age of 30 years using various sway meters, and optical systems, particularly when subjects close their eyes (Baloh et al., 1998; Maki, Holliday & Fernie, 1990; Sheldon, 1963). However, it has been pointed out that above assessments of the body sway pattern depends largely on the tester's subjectivity and there is not much objectivity (Shimada et al., 2003). Even healthy elderly show a larger body sway than is evident in young adults assessed with an electronic force platform which identified the location of their CoG every 0.05 s (Brooke-Wavell et al., 2002). Piirtola & Era (2006) did a review to extract the findings of prospective studies where force platform measurements had been used as predictors of falls among elderly populations. They found that certain aspects of force platform data might have predictive value for subsequent falls, especially various indicators of the lateral control of posture. There is no clear consensus in the literature regarding gender differences in sway; although some studies report higher standing balance values in women compared with men in all age groups (Ekdahl, Jarnlo & Andersson, 1989), other authors have reported no significant differences (Hagemon, 1995). Era et al. (2006) found that deterioration in balance function clearly started at relatively young ages and further accelerated from at about 60 years upwards. They also found that due to systematic differences between males and females, separate normative values for both sexes were needed (Era et al., 2006).

The maintenance of postural stability is a highly complex skill which is dependent on the coordination of a vast number of neurophysiologic and biomechanical variables. Its decrease in older people may be explained by deficits in muscle strength mentioned in the previous section (Daubney & Culham, 1999; Iverson et al., 1990; Lord, Clark & Webster, 1991; Wolfson et al., 1995), (2.5.1) reduced peripheral sensation (Duncan et al., 1992), (2.5.2) poor visual acuity (Lord et al., 1991), (2.5.3) vestibular function, and (2.5.4) central processing of afferent inputs explained through slowed reaction time (Lord et al., 1991).

2.5.1 Peripheral function

Peripheral function is clinically assessed by measuring joint position or movement sense (proprioception) and the perception of light touch or vibratory stimuli. Clinical assessments include measuring the ability of a patient to detect the direction of clinician-induced movements, feel a pin prick, a light touch from an aesthesiometer hair, or a vibration produced by a tuning fork. More quantitative assessments involve tests of judgement of knee and ankle joint position and movement, and threshold tests of tactile and vibratory sensitivity (Lord et al., 1991).

Many investigators, using numerous vibrating stimuli, placed on a various parts of the body, have consistently found age-related declines in vibration sense to all vibration frequencies greater than 50Hz (Kenshalo, 1986; Lord et al., 1991). In Kenshalo’s (1986) study, comparisons of the elderly and young groups showed that elderly persons were significantly less sensitive than young individuals to mechanical stimuli (tactile and vibration) at both sites. No significant differences were found in thresholds to thermal stimuli (warm, cold, and heat pain) at either site except elderly feet were significantly less sensitive than young feet to warm stimuli. Kenshalo (1986) also found that vibration sense was poorer in the lower limb compared with the upper limb at all ages and showed a greater age-related decline. The cutaneous and subcutaneous mechanoreceptors that innervate glabrous or hairless skin are the rapidly adapting Meissner’s corpuscles (stroking) and Pacinian corpuscles (vibration) and the slowly adapting Merkel disk (pressure) and Ruffini endings (skin stretch). These receptors, in combination with hair cells, deliver important feedback about the environment and can supplement joint position sense and movement detection. Ageing has been shown to reduce the number of Pacinian and Meissner's receptors with a corresponding decrease in vibration perception and touch thresholds (Verrillo, Bolanowski & Gescheider, 2002).

Although there are comparatively few studies on the effect of age on tactile sensitivity, most reports indicate that the tactile sensitivity, as measures by aesthesiometer or by two-point discrimination, decreases significantly with age (Lord, Lloyd & Li, 1996), and is reduced in the lower limb compared with the upper limb (Halar et al., 1987). Lord et al. (1996) performed a multiple regression analyses in 183 community-dwelling women aged 22-99 years which revealed that tactile sensitivity and vibration sense were significant predictors for one or more of the gait parameters (e.g. walking speed, stride length and cadence), elucidating the relative importance of specific physiological systems in the maintenance of normal gait, and supporting the claim by Duncan et al. (1993) that the age-related decline in mobility is related to impairments in multiple domains. Halar et al. (1987) used five semi objective devices for testing sensory perception thresholds on 36 normal subjects to determine normal threshold values, intersubject variability, and their correlation with age. Each subject was tested at 12 upper extremity and ten lower extremity sites, and results showed that the mean threshold for each sensory perception modality in the upper extremity sites was significantly lower than in the lower extremity. Moreover, the means of most sites tested for each sensory modality (except vibration) showed correlation with age.

Clinical studies which have investigated whether there is a decline in joint position sense beyond 65 years of age have produced inconsistent results (Lord et al., 2001). This may due at least in part to the imprecision of the tests used, which have been based on subject's ability to identify experimenter-induced movements of body parts. However, more recent investigations assessing position sense of the ankle joint when weight bearing have also reported an increased threshold for movement detection with age. Proprioception is more accurate during weight bearing due to the increase in receptor activation. For example, Thelen et al. (1998) compared the ability of young and older women to detect dorsiflexion and plantarflexion movements of the foot when weight bearing on a moveable platform, and reported that the threshold for movement detection was 3-4 times larger in the older group, due to a reduced capacity to detect small sagital-plane rotations of the foot in an upright stance.

Another study by Richardson, Ching & Hurvitz (1992) found a strong association between electromyography documented polyneuropathy involving the lower extremities and falls. Richardson et al. (1992) suggested that the failure to find a relationship between peripheral neuropathy and falling in previous reports may due to the limited accuracy of clinical examinations in diagnosing neuropathy. On the other hand, in a large prospective community study, Lord et al. (1994) found that tactile sensitivity at the lateral malleolus was inferior in fallers compared with nonfallers. They also found that fallers demonstrated reduced vibration sense at the tibial tuberosity and impaired lower limb proprioception compared with nonfallers (Lord et al., 1994). Sensitivity and proprioception contribute to postural control, which is a global measure of stability.

Thus it seems that reduced peripheral sensation is associated with falls, but that such an association only emerges when the measures of peripheral sensation are accurately and quantitatively ascertained.

2.5.2 Visual acuity

In addition to allowing the individual to detect specific environmental hazards, vision provides information about the position and movements of our bodies in relation to the external environment, and is thus an important source of information for postural control. Many researchers have found that various visual functions including visual acuity, contrast sensitivity, glare sensitivity, dark adaptation, accommodation and depth perception decline significantly with age, especially beyond 40 years (Lord et al., 2001; Rousselet et al., 2009). In humans, there is evidence that ageing affects a large range of visual processing tasks (Schieber, 2006), including orientation discrimination (Betts, Sekuler & Bennett, 2007), motion perception (Billino, Bremmer & Gegenfurtner, 2008), contour integration (Roudaia Bennett & Sekuler, 2008), and face and object visual processing (Habak, Wilkinson & Wilson, 2008). Despite changes in optical factors in the retina, and in the lateral geniculate nuclei of the thalamus (LGN), declines in visual functions with age are mediated, to a large extent, by cortical changes (Rousselet et al., 2009).

In a large cross-sectional survey of eye disease with retrospective collection of falls data, Ivers et al. (1998) found that impaired visual acuity was associated with a history of recurrent falls. Similarly, Nevitt et al. (1989) also found that poor visual acuity was a risk factor for recurrent falls in a prospective cohort study. Campbell et al. (1989) found a significant association between visual acuity and falls in a large sample of community-dwelling older people, but this association was lost when adjusting for age.

In contrast, Robbins et al. (1989) found no association between visual acuity and falls in age-groups above 65 years.

However, a number of previous studies (Ivers et al, 1998; Klein et al., 1998) examining the relationship between impaired vision and risk of falls have utilized cross-sectional and retrospective designs and have been limited in their ability to control for potential confounding factors. Lord & Dayhew (2001) reported in a prospective study of 148 community-dwelling individuals that impaired vision is an important and independent risk factor for falls. The same authors (Lord & Dayhew, 2001) reported that there is an increased risk of falling in subjects with binocular visual acuity of 6/10 or worse. Although recently measured visual acuity is relevant for screening purposes, declines in visual acuity may be scientifically interesting as a reflection of adaptation. That is, there may be an increased risk of falling if visual acuity has recently declined, as elderly subjects may not be as successful in adapting to changes in their visual acuity, whereas subjects with worse baseline acuity may have adapted at a time when their coordination and reflexes were better.

As a consequence, it could be expected that an impairment in visual acuity could deteriorate the ability to perceive edges in the environments such as steps, gutters and pavement cracks, contributing to trips in older people.

2.5.3 Vestibular function

The vestibular system contributes to posture by maintaining the reflex arc keeping the head and neck in the vertical position and by corrective movements elicited through the vestibule-ocular and vestibule-spinal pathways (Stelmach & Worringham, 1985). In spite of the age-related decline in function, there are no reports of an association between impaired vestibular function and either instability or falls in older people. Lord et al. (1991; 1994) found that vestibular function was not related to stability or falls. It may be that older people with adequate peripheral sensation and/or vision can compensate for reduced vestibular functioning. However, the screening assessments used to measure vestibular function in the epidemiological studies of falls undertaken to date (response to a slow tilt, ability to write vertically or remain in place when undertaking a stepping test with the eyes closed), have been indirect and possibly too insensitive to be able to detect significant impairments in vestibular function (Lord et al., 2001).

2.5.4 Reaction time

When a person is subject to a postural challenge or threat, the ability to react quickly and appropriately is important for avoiding falls. There is approximately a 25% increase in simple reaction time from the twenties to the sixties, with further significant slowing beyond this age (Fozard et al., 1994). Slower reaction times in older adults may be due to the changes in the central and peripheral nervous systems (Sturnieks, St George & Lord, 2008). With increasing age, there are fewer neurons within the nervous system and the human brain loses 10% of its weight by the age of 90 years. In addition, there is also an age-related loss of myelin, the substance that surrounds neuronal axons and increases the speed of conduction of action potentials. Numerous other age-related changes can occur in the nervous system with the overall effect being a slowing and/or depressed frequency of signals to and from effector organs. The implications of these changes include impaired sensory acuity, poor integration and slowed or depressed motor responses. Slowed muscle latencies and increased difficulty in producing and coordinating muscle force may also contribute to slower reaction times in older adults (Sturnieks et al., 2008).

It has also been found that fallers record significantly slower reaction times than non-fallers in both simple and choice reaction time tests that involve more complicated motor responses, such as extending and flexing the knee, and stepping from either foot (Grabiner & Jahnigen, 1992; Lord & Fitzpatrick, 2001). These findings suggest that both decision and movement time are increased in older people at risk of falls.

2.6 Gait deficits

Normal gait distinguishes between two phases: stance and swing phase. In terms of duration, the *stance phase* constitutes about the 60% of the gait cycle during walking (Mann & Mann, 1997). The *swing phase* begins with the toe-off and ends with a heel-strike, comprising about the 40% of the cycle. The duration of each phase should be the same for both limbs to account for normal gait symmetry and rhythm (Mann & Mann, 1997). Abnormality of gait is usually a consequence of pain, weakness, or a difference in limb length (Sudarsky, 1990).

The maintenance of balance during walking represents a considerable challenge to the postural control system. Locomotion can be regarded as consisting of four main subtasks: (a) the generation of continuous movement to progress towards a destination; (b) maintenance of equilibrium during progressions; (c) adaptability to meet any changes in the environment, and (d) the initiation and termination of locomotor movements (Woollacott & Tang, 1997). Each of these tasks is heavily reliant on both the ability to generate force, and the appropriate integration of afferent input from the extremities (Dietz, 1986).

Gait stability, defined as the ability to walk safely and independently, is critical to maintaining independence in activities of daily living, in preserving social relationships and in ensuring quality of life (Fried et al., 2000; Guralnik et al., 1995; Iezzoni et al., 2000; Shumway-Cook et al., 2007). Walking in daily life involves negotiating diverse environments with varying terrains (cluttered, slippery), ambient conditions (adverse weather, low light), and attentional demands (noisy or distracting environments). In addition, walking is often performed in conjunction with other tasks such as carrying loads, scanning the environment, changing directions, avoiding obstacles, or engaging in social interactions. Evaluation of mobility in older adults typically involves observing their speed, stability, step length, and foot clearance during self-paced walks performed on straight, uncluttered, and well-lit courses (Shumway-Cook et al., 2007). It has been suggested that the neural control of walking involves three conceptually different tasks: (a) generation of a rhythmic locomotor pattern for progression, (b) control of equilibrium, and (c) the capacity to adapt gait to accommodate behavioural goals and environmental context (Forssberg, Grillner & Halbertsma, 1980).

Numerous studies have documented that balance and locomotor adaptation tend to become impaired with age. Several researchers have shown an age-related decline in mediolateral control of the centre of mass, resulting in decreased stability in the frontal plane in older adults (Chou et al., 2003; Shumway-Cook et al., 2007). In addition, an increase in the two-legged support time during walking was related to a decline of balance ability with ageing (Schmid et al., 2007). Given that ageing is associated with declines in both sensory function and muscle strength, it is clear that gait patterns will change with age and may be associated with postural instability (Sudarsky, 1990), thus associated to an increased risk of falling (Guralnik et al., 1995; Heitmann et al., 1989; Shumway-Cook et al., 2007; Tinetti et al., 1988). As stated previously, factors that contribute to increased risk of falls in the elderly include decrements in lower extremity strength and power and certain characteristics of gait (Perell et al., 2001). Lee & Kerrigan (1999) reported that fallers exhibited significantly lower peak torque during ankle dorsiflexion, plantar flexion, inversion, eversion, and hip adduction. These joint movements are thought to play a role in the control of postural stability. Ankle plantar flexion power is associated with step length reductions and reductions in gait velocity in older adults (Judge, Davis & Ounpuu, 1996). Lord et al. (1991) found that recurrent fallers had significantly slower and more variable cadence than both one-time fallers and nonfallers and that reduced quadriceps strength was also associated with slow walking speed.

A number of kinematic and kinetic studies have been undertaken to evaluate differences in gait patterns between young people and older people. The most consistent finding of these studies is that older people walk more slowly than young adults (Buchner et al., 1996a; Lord et al., 1996), which has been found to be a function of both a shorter step length (Lord et al., 1996; Winter et al., 1990) and increased time spent in double limb support, this has been linked to tentative gait (Lord et al., 1996). Lord et al. (1996) found that walking speed, stride length and cadence declined with age with corresponding increases in stance duration and percentage of the stride in the stance phase. Gait speed has a high correlation with leg muscle strength and balance function (Schmid et al., 2007; Studenski et al., 2003). Shumway-Cook et al. (2007) showed that the decline in gait speed was greater at aged 65 and older.

2.7 Functional performance assessment

Functional decline is an important part of health care of the elderly. The following section aims to review the most common functional performance assessment tools used in the literature, in order to identify older people at risk of developing disability.

The risk factors identified in an assessment may be modifiable (such as muscle weakness, balance and gait problems, multiple drug therapy, or hypotension) or non-modifiable (such as blindness, stroke, or diabetes). In an elderly population, the risk of becoming dependent in activities of daily living increases exponentially as the number of associated risks rises (Nevitt et al., 1989; Tinetti, 2003); thus an effective and efficient clinical strategy for risk assessment and management must address many predisposing and precipitating factors.

The assessment of physical functioning is an important component in the evaluation of community-dwelling older persons. Standardized tests of physical performance have been employed in recent years. These measures have been shown to predict outcomes such as falls, institutionalization, and death (Berg et al., 1992; Boulgarides et al., 2003; Duncan et al., 1990; Guralnik et al., 1994; Lord & Fitzpatrick, 2001; Medell &

Alexander, 2000; Perell et al., 2001; Shumway-Cook et al., 2007; Tinetti, 1986; Tinetti et al., 1988; Wall et al., 2000; Whitney, Hudak & Marchetti, 2000). A number of physical performance screening tests have been found to be reliable and valid to assess functional decline amongst people living in residential homes (Berg et al., 1992; Podsiadlo & Richardson, 1991; Tinetti, 1986; Whitney et al., 2000), however, these same tests have proven to be less reliable amongst senior citizens who live independently mainly due to achieving high scores in such instruments without being able to detect less plausible function limitations (Boulgarides et al., 2003; Mathias, Nayak & Isaacs, 1986; Whitney et al., 2000).

Other tests do not assess physical performance other than gait and balance (Berg et al., 1992; Boulgarides et al., 2003; Perell et al., 2001; Tinetti, 1986; Wall et al., 2000; Whitney et al., 2000), or only balance (Duncan et al., 1992; Medell & Alexander, 2000), reaction time (Lord & Fitzpatrick, 2001), lower extremity function (Guralnik et al., 1994; Guralnik et al., 1995), and gait through complex walking tasks (Shumway-Cook et al., 2007). Several tests have been developed to measure mobility and balance, and most of these have been useful in identifying older people at risk of falls (Berg et al., 1992; Podsiadlo & Richardson, 1991; Tinetti, 1986). These tests can be categorised as tests that measure impaired stability when standing, impaired stability when leaning and reaching, inadequate responses to external perturbations, slow voluntary stepping, impaired gait and mobility, impaired ability in standing up, and impaired ability with transfers (Lord et al., 2001). For detailed description of the tests mentioned above see summary appendix I. Table 2.7.1 illustrates the most frequently reported tools of balance and gait administered in the community dwelling elderly population.

The “Get Up and Go” test that had the subject rise from a chair, walk 3m, turn around, return to the chair, and sit down (Mathias et al., 1986); performance was graded on a 5-point Likert scale. To overcome the subjectivity involved in administering such a scale, the test was modified to include the time taken to complete the test: the “Timed Get Up and Go” test (TGUG) (Podsiadlo & Richardson, 1991), which is the first instrument mentioned in table 2.7.1. The TGUG test only measures the time to complete the test, masking the problems a subject might have in doing one or more of the tasks included in the test. Although the TGUG test demonstrated good reliability (Podsiadlo & Richardson, 1991) and moderate correlation to the scores on the Berg Balance Scale and gait speed, subjects studied were a low-function institutionalized population (Podsiadlo & Richardson, 1991).

In appendix I there is a detailed list of tests used to assess functional performance in elderly people, in chronological order of publication or, in some cases, according to the first reference found. In 2004, the Royal College of Nursing published an evidence review of functional performance assessment tools of 17 studies (out of 223 previously screened for relevance). The following tests were selected taking into account the Royal College of Nursing review (2004) and also, other tests used in the literature to assess functional performance were also included.

Table 2.7.1

Most frequently used tests of balance and gait

Name of the test
Timed Get Up and Go
Turn 180º
Performance Oriented Mobility Assessment (Tinetti scale)
Functional reach
Dynamic gait index
Berg balance scale

The majority of these tests, including such measures as SLB, SPPB, and FRT, assess the ability to maintain a position in front of imbalance perturbations. This ability to maintain stance is based on a series of corrective arm, trunk, and leg responses while maintaining the feet in place (Cho et al., 2004). Other test batteries have been designed to assess overall mobility, balance and gait disorders, and ultimately fall risk, including tests such as the TUGT, POMA or BBS.

Nevertheless, none of the abovementioned tests focused on the ability to take a step, a response which is present when the strategies to maintain a position are insufficient. Trips and slips are common contributors to older adult falls and responding to a slip or trip requires taking a step. Recent studies have examined stepping in older adults. In response to externally applied perturbations of stance, older adults differ from young adults in the number of steps used to respond and the ability to successfully recover with a step in response to increasing perturbation magnitudes (Luchies et al., 1994; Medell & Alexander, 2000).

An ability to identify sedentary, community-dwelling older people at risk of developing disability is needed in order to target high-risk individuals for preventive intervention.

2.8 Interventions to reduce functional decline

The scope of the following section is restricted to review the interventions aimed to reduce functional decline in the elderly population, as well as in the frail elderly.

In old age, reduction in physical function can lead to a loss of independence, the need for hospital and long-term nursing-home care, and premature death. The importance of physical, functional, psychological, and social factors in realising a healthy old age is recognised by elderly people, health-care professionals, and policy makers. The risk factors for reduced physical function in elderly people, as identified in longitudinal studies, relate to comorbidities, physical and psychosocial health, environmental conditions, social circumstances, nutrition, and lifestyle. The need for a preventive strategy based around identification and treatment of diverse risk factors was identified more than 40 years ago, and many trials of intervention packages have been reported and reviewed (Beswick et al., 2008).

Trials have focused on general and frail elderly populations, elderly people discharged from hospital, and those at risk of falling. However, the development of risk factors, admission to hospital, and risk of falling represent a common chain of experiences for many elderly people. Likewise, multifactorial interventions in these populations have common characteristics and, in addition to targeting specific outcomes relating to hospital readmissions and falls, share the common aims of physical function maintenance, disability limitation, and promotion of independence.

Interventions designed to prevent functional decline have the potential not only to generate large health care savings but also to lead to important reductions in the physical, emotional, social, and financial problems attributable to disability. Because elderly persons with impairments in physical abilities, such as reduction in strength and impaired balance, are at high risk for the development of functional decline (Gill et al., 2002; Guralnik et al., 1995), they may be particularly good candidates for preventive interventions. Consistent, life-long exercise training constitutes a powerful input for producing a broad range of positive long-term health benefits by offsetting the development of chronic disease and conditions, such as reduced probability of cardiovascular diseases, diabetes, some types of cancers, and all-cause mortality

(Chodzko-Zajko et al., 2009; Thompson et al., 2003). Moreover, several randomized trials have suggested a positive effect of engaging in regular physical activity on improving physical function and/or reducing symptoms of disability (Cress et al., 1999; Fiatarone et al., 1994; Nelson et al., 2004).

Regular participation in physical activity is integral to the maintenance of good health and functional independence in older adulthood. Conversely, physical inactivity doubles the risk of developing a disability that will adversely affect mobility as well as the ability to perform even the most basic activities of daily life. It has been recently demonstrated that individuals who regularly engage in any physical activity with an energy expenditure of at least 2700 kcal/wk were more likely to delay the onset of frailty for a period of 5 years compared with those who were sedentary (Peterson et al., 2009). This downward spiral in physical function will ultimately increase the older adult's risk for falls (Gardner, Robertson & Campbell, 2000).

Much attention has been focused on regular physical activity as a means to enhance health and maintain function in old age, and several exercise programs have been designed to improve the parameters of fitness and, in turn, enhance function (Chodzko-Zajko et al., 2009). In its primary role, regular engagement in physical activity can delay the onset of pathology and system impairments that may lead to disability and heightened risk for falls. For older adults identified at moderate to high risk for functional decline, physical activity serves a secondary role by slowing the progression of disease and systemic impairments that limit an older adult's ability to perform many daily activities independently. Its tertiary role lies in the restoration of function to a level that allows for more autonomy in the performance of daily activities (Freedman et al., 2006). Medical care for older adults needs to include treatment of pathologic causes of progressive weakness, weight loss, decreased exercise tolerance, slowed task performance (i.e. walking speed), and/or low activity (Fried et al., 2004). Treatment should include attention to minimizing further loss of weight, balance impairments and gait disorders, and muscle strength, which are hallmarks of frailty and risk factors for resulting disability (Fried et al., 2004).

At this level of risk, programs also need to be more tailored to the individual needs of participants and incorporate specific balance and gait activities, coupled with functional activities designed to improve muscular strength (Lord et al., 2003; Rose, 2003; Rubenstein et al., 2000). Rubenstein et al. (2000) randomly assigned 59 community-living men (mean age = 74 years) with specific fall risk factors (i.e., leg weakness, impaired gait or balance, previous falls) to a control group (n = 28) or to a 12-week group exercise program (n = 31). Exercisers showed significant improvement in measures of endurance and gait. Measures of strength assessed with isokinetic dynamometry increased 21% for right knee flexion and 26% for extension compared to the control group, had a 10% increase ($p < .05$) in distance walked in six minutes, and improved ($p < .05$) scores on an observational gait scale.

Gillespie et al. (2003) assessed the effects of interventions designed to reduce the incidence of falls in elderly people living in the community, or in institutional or hospital care. Sixty two trials involving 21.668 people were included. Interventions likely to be beneficial were: (a) multidisciplinary, multifactorial, health/ environmental risk factor screening/ intervention programmes in the community and in residential care facilities; (b) a programme of muscle strengthening and balance retraining, individually prescribed at home by a trained health professional; (c) home hazard assessment and modification that is professionally prescribed for older people with a history of falling; (d) withdrawal of psychotropic medication; (e) cardiac pacing for fallers with cardio inhibitory carotid sinus hypersensitivity; and (f) Tai Chi group exercise intervention.

Beswick et al. (2008) searched systematically for randomised controlled trials assessing community based multifactorial interventions in elderly people (mean age at least 65 years) living at home with at least 6 months of follow-up. Outcomes studied were: living at home, death, nursing-home and hospital admissions, falls, and physical function. They identified 89 trials including 97.984 people. Interventions reduced the risk of not living at home (RR 0.95, 95% CI 0.93-0.97). Interventions also reduced nursing-home admissions (0.87, 0.83-0.90), but not death (1.00, 0.97-1.02). Risk of hospital admissions (0.94, 0.91-0.97) and falls (0.90, 0.86-0.95) were reduced, and physical function (standardised mean difference -0.08, -0.11 to -0.06) was better in the intervention groups than in other groups. Benefit for any specific type or intensity of intervention was not noted. In populations with increased death rates, interventions were associated with reduced nursing-home admission.

In a recent study, thirty elderly women aged 62 to 86 were subjected to a two-year authorized physical activity program. Peripheral blood lymphocytes distribution and the production of cytokines involved in the immune response development and regulation were investigated. The same parameters were evaluated in two control groups of women: (a) a sedentary group of 12 elderly women selected for the second round of the physical activity program and in (b) a group of 20 sedentary young women. Their results suggested that moderate, long-term physical activity in elderly women increased immune response development and regulation, thus improving health status (Drela, Kozdron & Szczypiorski, 2004).

Strength training seems to be highly effective for eliciting increases in muscle size, efferent neural motor drive, maximal muscle strength, and contractile rate of force development, not only in young subjects, but also in elderly men and women (Drewnowski & Evans, 2001; Fiatarone et al., 1994; Rogers & Evans, 1993; Suetta et al., 2004), and it can also improve balance and gait speed in very old and frail nursing home residents (Drewnowski & Evans, 2001). The ability to develop a rapid rise in muscle strength (i.e., a high rate of force development (RFD)) in elderly individuals, is reduced compared with young individuals of both genders (Thelen et al., 1996); however, combined power/strength training has been shown to induce marked increases in RFD and muscle activation assessed with electromyogram (EMG) amplitude in healthy, elderly individuals of both genders (Hakkinen et al., 2001). Suetta et al. (2004) demonstrated that strength training was an effective way to increase muscle mass, muscle activation, and rapid muscle force characteristics (RFD) in elderly individuals rehabilitating after a long-term disuse. Previous studies had demonstrated positive effects of strength training on muscle strength in healthy elderly individuals (Lexell et al., 1995) and in very old subjects (Harridge, Kryger & Stensgaard, 1999). However, none of these studies had reported results on muscle size or neuromuscular adaptations with training. These improvements may often be limited in absolute terms, the corresponding enhancement in functional capacity sometimes is also lacking. It seems likely that for people with a low baseline level of strength, strength training will lead to improved functional abilities (Buchner et al., 1992). For detailed descriptions of studies see summary appendix II.

Recently, resistance training has been suggested especially for the elderly population, because of its better effect on the functional capacity to perform activities of daily living regardless of health status. However, evidence on whether the exercises intensity should be higher or lower is lacking. Seynnes et al. (2004) found that physiologic capacity (muscle strength and endurance) and 6-minute walking distance increased significantly more after high intensity (HI) resistance training (at 80% of their 1RM) than after low-moderate intensity (LI) training (at 40% of their 1RM), with a trend in the same direction for other measures of functional limitations (chair-rising time and stair-climbing power). These results indicate a dose-response relationship between the intensity of training and strength improvements, and between strength gains and functional performance.

Previous work had shown that functional status in elderly persons was associated with muscle endurance (Foldvari et al., 2000) in addition to other physiologic characteristics. Therefore, Seynnes et al. (2004) findings that muscle endurance increased significantly more in the HI than in the LI group, analogous to the findings with muscle strength, may have benefit for other tasks of daily living that require a longer duration of muscular exertion than those measured in their study (e.g., chair rising, stair climbing and six-minute walking). Their results differ from previous dose-response studies of training intensity in elderly persons. Authors including Hortobágyi et al. (2001) or Vincent et al. (2002) have compared intensities of resistance training that were similar to Seynnes et al. (2004) study. None of these studies found significant differences in muscle strength after moderate-intensity or HI machine-based training ranging from 10 to 52 weeks in healthy elderly persons. However, these studies preclude conclusions based solely on the variable of interest, intensity, because the lower intensity was partly compensated for by increasing the volume of training (number of repetitions in these protocols). It is noteworthy that knee extensor strength gains in these other studies were similar or lower to those observed in Seynnes et al. (2004) investigation, despite the fact that Seynnes et al. (2004) used free weights rather than machines. This may be explained by the use of nonoptimal training techniques such as the slow-progression model (Hortobágyi et al., 2001) or the single-set regimen (Vincent et al., 2002). In contrast, Seynnes et al. (2004) adjusted the intensity of exercise each week throughout the trial and used 3 sets per session.

Other studies have reported functional improvements after LI resistance training, but these studies have also included balance training (Brown et al., 2000) or involved several different exercises (Vincent et al., 2002). In Seynnes et al. (2004) investigation, both LI and HI regimens of resistance training exercise elicited similar and significant improvements in two measures of functional performance (stair climbing and chair rising). This finding would support the proposed curvilinear relationship between strength and function advanced by Buchner et al. (1996b). Functional benefits have been demonstrated when strength training is undertaken in combination with other types of training. Together, these analyses support the hypothesis that LI resistance training has less robust effects on functional impairments than does HI training.

Research also indicates that balance exercise programs can improve postural balance in older adults (Howe et al., 2007; Islam et al., 2004). Judge et al. (1993) showed that a combined program of resistance training, walking, flexibility and balance improved single-stance postural sway in older women, and that flexibility-based training didn't demonstrate significant differences. Its results should be taken as preliminary, because the sample was low (n = 21), women were healthy and young elderly (68 ± 3.5 years), and all participants were willing to participate.

The use of unstable surfaces such as foam pads, balance boards and exercise balls, increase muscle activation and speed of contraction more than stable surfaces, thus challenging not only balance, but also lower-body strength (Bullock-Saxton, Janda & Bullock, 1993). It is likely that the unstable surfaces require greater muscle activation to counteract increased sway. In a Cochrane review, Howe et al. (2007) reported that interventions involving gait, balance, coordination and functional exercises, and muscle strengthening had the greatest impact on indirect measures of balance. However, there was limited evidence that effects were long-lasting. For detailed descriptions of studies see summary appendix II.

Although there have been traditional literature reviews describing studies designed to improve balance and muscle strengthening in the elderly, there is still uncertainty surrounding the efficacy of exercise interventions, the effectiveness of the dosage (frequency, duration, or intensity of delivery), setting in which the intervention takes place, level and type of supervision, or indeed who is the most likely to benefit.

Previous intervention studies targeting frail older people have focused on using general interventions such as comprehensive geriatric assessment (Cohen et al., 2002; Melis et al., 2008) and rehabilitation models (Ollonqvist et al., 2007), with inconclusive effects on functional ability and well-being. Exercise programs for frail older people have yielded conflicting results. A systematic review of physical training in institutionalized elderly indicated positive effects on muscle strength but effects on gait, disability, balance and endurance were inconclusive (Rydwik, Frandin & Akner, 2004). In one study, an exercise program in very frail older people resulted in no improvements in self-reported physical health and function (e.g. walking, bathing, upper- and lower-body dressing, transferring from a chair to a standing position, using the toilet, eating, and grooming) (Gill et al., 2002). However, the same study provided evidence that could prevent functional decline in this population (Gill et al., 2002).

In contrast, in a randomized controlled trial of a 10-week resistance exercise program among 100 frail nursing home residents, Fiatarone et al. (1994) demonstrated significant increases in muscle strength, gait velocity, stair-climbing power and level of spontaneous physical activity in the exercisers compared with the controls, conferring its greatest benefits to improvements in health status to those who were more frail. Another study concluded that exercise improved physical performance scores assessed with the modified Physical Performance Test (modified PPT) score and performance of ADL as measured by the Older Americans Resources and Services instrument, and the Functional Status Questionnaire (FSQ), although it is possible that the increased level of socialization enhanced the motivation of exercise training participants to a greater extent than that of control participants and could account for some of the improvements observed, particularly in self-reported measures (Binder et al., 2002). A recent systematic review found community-based, multifactorial interventions reduced hospital admission in the frail population, but did not significantly benefit physical function in this group mainly due to heterogeneity in those selected as frail and to weak evidence of benefit (Beswick et al., 2008). As said, specific interventions targeting physical activity have been shown to improve physical function in the frail elderly population (Binder et al., 2002; Fiatarone et al., 1994; Gill et al., 2002). For detailed descriptions of studies see summary appendix II.

Attempts have been made to improve clinical outcomes for frail older people, however no interventions have been developed to specifically delay the syndrome of frailty. In conclusion, although the extensive literature on exercise interventions to prevent functional decline provides many insights, there is no clear message about which exercise interventions are more effective in reducing frailty physical components such as strength, balance and mobility, in frail elders.

3. AIMS AND HYPOTHESES

The **aims** of the study were:

1. To measure the sensitivity of a modified version of the TGUG test in predicting fall risk in elderly individuals.

2. To determine the degree to which scores of the modified TGUG test correlated with other measures typically used in the literature to document age-related change in both functional performance and physiological impairment (concurrent criterion validity).

3. To determine the effect of a 12-week structured, intervention program on reducing physical frailty measures in a group of community-dwelling physically frail elderly individuals. The secondary aim of the study was to evaluate whether these improvements were sustained 6 months after the end of the training program.

The aforementioned aims were based on three initial work **hypotheses**:

1. The modified TGUG test will be sensitive to discriminate older individuals of high and low functional levels; and shows a good inter-tester reliability from both a quantitative and qualitative perspective.

2. The modified TGUG test will significantly correlate to other balance and strength measures typically used in the literature to document the age-related decline in function (e.g. performance oriented mobility assessment, single-leg balance, normal and fast gait speed, chair rises, and isometric dynamometry).

3. A functional circuit training program focused on functional balance and lower body strength-based exercises will significantly reduce physical frailty components relative to those in a control group.

4. METHODS AND RESULTS

The dissertation is based on the result of three different projects carried out during the Physical Activity and Sports Sciences Doctorate Program at the FPCEE Blanquerna (Universitat Ramon Llull) of Barcelona. The following articles have been published in international journals, as a result of the work performed.

1. Giné-Garriga M, Guerra M, Marí-Dell'Olmo M, Martin C, Unnithan VB. Sensitivity of a modified version of the 'Timed Get Up and Go' Test to predict fall risk in the elderly: a pilot study. *Archives of Gerontology and Geriatrics* 2009; 49: e60-66. (doi:10.1016/j.archger.2008.08.014).

2. Giné-Garriga M, Guerra M, Manini TM, Marí-Dell'Olmo M, Pagès E, Unnithan VB. Measuring Balance, Lower Extremity Strength and Gait in the Elderly: Construct Validation of an Instrument. *Archives of Gerontology and Geriatrics* [In press].

3. Giné-Garriga M, Guerra M, Pagès E, Manini TM, Jiménez R, Unnithan VB. The effect of functional circuit training on physical frailty in frail older adults: a randomized controlled trial. *Journal of Aging and Physical Activity* [In press].

4.1 Publication one

Giné-Garriga M, Guerra M, Marí-Dell'Olmo M, Martin C, Unnithan VB. Sensitivity of a modified version of the 'Timed Get Up and Go' Test to predict fall risk in the elderly: a pilot study. *Archives of Gerontology and Geriatrics* 2009; 49: e60-66. (doi:10.1016/j.archger.2008.08.014).

Archives of Gerontology and Geriatrics 49 (2009) e60–e66

Contents lists available at ScienceDirect

Archives of Gerontology and Geriatrics

journal homepage: www.elsevier.com/locate/archger

Sensitivity of a modified version of the 'timed get up and go' test to predict fall risk in the elderly: A pilot study

Maria Giné-Garriga [a,b], Míriam Guerra [a], Marc Marí-Dell'Olmo [c,d], Carme Martin [a,b], Viswanath B. Unnithan [e,*]

[a] FPCEE Blanquerna, Universitat Ramon Llull, Department of Physical Activity and Sport Sciences, Císter 34, 08022 Barcelona, Spain
[b] Primary Health Care of Barcelona, Department of Physical Activity and Health, Institut Català de la Salut, Esteve Terrades 30, 08023 Barcelona, Spain
[c] IDIAP Jordi Gol, Primary Healthcare Research Institution, Gran Via de les Corts Catalanes 587, 08007 Barcelona, Spain
[d] CIBER of Epidemiology and Public Health (CIBERESP), Agència de Salut Pública, Plaça Lesseps 1, 08023 Barcelona, Spain
[e] Sport Department, Deanery of Sciences and Social Sciences, Liverpool Hope University, Hope Park, Liverpool L16 9JD, UK

ARTICLE INFO

Article history:
Received 19 May 2008
Received in revised form 8 August 2008
Accepted 27 August 2008
Available online 31 October 2008

Keywords:
Fall prevention in elderly
Assessment tool
Balance in elderly
Gait functions in elderly

ABSTRACT

The purpose of this study was to assess the sensitivity of a modified version of the 'Timed Get Up and Go' (TGUG) test in predicting fall risk in elderly individuals, using both a quantitative and qualitative approach in individuals older than 65 years. Ten subjects (83.4 ± 4.5 years) undertook the test twice. To assess inter-rater reliability, three investigators timed the two trials using a stopwatch (quantitative). The reproducibility of a qualitative evaluation of the trials was accomplished by the completion of an assessment questionnaire (AQ) at each trial by three investigators. To assess the agreement between the three investigators, the coefficients of reliability (CR), intra-class correlation coefficients (ICC) and limits of agreement were determined for the total time to do the test (TT). The weighted Kappa K of Cohen and ICC was calculated for the AQ. Inter-group comparison: 60 subjects (74.2 ± 4.9 years) were divided equally into four groups: (1) sedentary with previous history of falls, (2) sedentary without history of falls, (3) active with history of falls, and (4) active without history of falls. All of them undertook the modified TGUG test once. One investigator undertook the timing and completed the AQ. CR values for the TT were above 98% and with ICC of TT = 0.999. The differences in TT between the three investigators' measures ranged from 0.19–0.55 s S.D. of the mean difference. Weighted Kappa K of Cohen ranged 0.835–0.976, with ICC of AQ = 0.954. *Inter-group comparison study.* Significant differences ($p < 0.05$) were noted between the mean score of TT of Group 4 and the rest of the groups, and between Groups 2 and 1. Significant differences ($p < 0.05$) were noted between the mean score of points obtained in the AQ of Group 1 and the rest of the groups. The modified version of the TGUG test demonstrated good sensitivity for detecting fall risk in elderly individuals, and good inter-tester reliability from both a quantitative and qualitative perspective.

1. Introduction

Falls are among the most common and serious problems facing elderly persons. Falling is associated with increased mortality, morbidity, reduced functioning, loss of independence and premature hospital and geriatric admissions (Brown, 1999; Perell et al., 2001; Ciccarelli, 2006). Moreover, falls are the most common cause of accident amongst persons over 65, representing the main cause of death by injury (Abrams and Berkow, 1990). Both the incidence of falls and the complications associated with falls increase considerably after the age of 60. An estimated 25%–35% of adults aged 65 years and older fall each year (Boulgarides et al., 2003; Tinetti, 2003; Royal College of Nursing, 2004). After the age of 75 years, the rates are higher (American Geriatrics Society et al., 2001).

The etiology of falls amongst senior citizens is generally considered multi-factorial, covering intrinsic and extrinsic circumstances. Since the risk of falling increases exponentially as the number of associated risks rises (Nevitt et al., 1989; Tinetti, 2003), an effective and efficient clinical strategy for risk assessment and management must address many predisposing and precipitating factors. The most likely intrinsic risk factors to cause a fall are: advanced age, chronic diseases, muscular weakness or reduced muscle mass, a previous history of falls, and deficits in gait and balance (Perell et al., 2001; Melzer et al., 2004; Royal College of Nursing, 2004). Muscular weakness is functionally defined as having difficulty standing up from a chair (Campbell et al., 1989). It is also

* Corresponding author. Tel.: +44 151 291 2045; fax: +44 151 291 3414.
E-mail address: unnithv@hope.ac.uk (V.B. Unnithan).

0167-4943/$ – see front matter © 2008 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.archger.2008.08.014

associated with a greater risk of suffering a fall (Campbell et al., 1989). Based on the available data, there are few tests that have been found to be strongly predictive of falls amongst active senior citizens who live independently.

A number of fall-risk screening tests have been found to be reliable and valid to identify the risk of falling amongst people living in residential homes (Tinetti, 1986; Podsiadlo and Richardson, 1991; Berg et al., 1992; Whitney et al., 2000), however, these same tests have proven to be less accurate when evaluating the risk of falls amongst senior citizens who live independently (Mathias et al., 1986; Whitney et al., 2000; Boulgarides et al., 2003). Very few tests have specifically tested the ability to predict falls, although all have provided standardized measures of disability and functional limitations. Typically, these measures do not assess intrinsic factors other than gait and balance (Tinetti, 1986; Podsiadlo and Richardson, 1991; Berg et al., 1992; Whitney et al., 2000; Perell et al., 2001). One such instrument was the "Get Up and Go" test that had the subject rise from a chair, walk 3 m, turn around, return to the chair, and sit down (Mathias et al., 1986). The performance was graded on a 5-point Likert scale. To overcome the subjectivity involved in administering such a scale, the test was modified to include the time taken to complete the test: the TGUG test (Podsiadlo and Richardson, 1991). Although the TGUG test demonstrated good reliability and moderate correlation to the scores on the Berg Balance Scale and gait speed, subjects studied were low-function institutionalized population (Podsiadlo and Richardson, 1991).

The modified TGUG test was designed to assess the four main risk factors associated with the risk of falling amongst people over the age of 65: (a) strength in lower extremities, (b) coordination, (c) balance and (d) gait, adding challenging tasks to predict fall risk in an active, non-institutionalized elderly population. Moreover, the TGUG test (Podsiadlo and Richardson, 1991) only measures the time to complete the test, masking the problems a subject might have in doing one or more of the tasks included in the test. The modified TGUG test measures not only the TT to complete the test, but also the time to achieve a series of tasks separately and includes an AQ (qualitative evaluation) in order to isolate the areas of functional deficit, thereby aiding the health professional in devising prevention strategies.

The aim of the study was to assess the sensitivity of a modified version of the TGUG test in predicting fall risk in elderly individuals.

2. Subjects and methods

2.1. Subjects

2.1.1. Reliability study

The sample used for the reliability study consisted of 10 subjects who volunteered to participate in the study. These subjects lived in a residential home in Barcelona and were all 65 years of age or older (2 men, 8 women; 83.4 ± 4.5 years; 1.58 ± 0.06 m; 61.9 ± 4.5 kg). The inclusion criteria were (a) being able to walk without any technical aid and (b) being able to follow simple orders. Based on the literature (Campbell et al., 1989), no gender effect was anticipated. A fall was defined as any disturbance of balance during routine activities that resulted in an unintentionally coming to rest on the ground or lower level with or without loss of consciousness (Reuben et al., 2002).

Written informed consent was obtained from all subjects of both the reliability and inter-group comparison study and a local university ethics committee gave approval for the study. The medical history of each subject in the sample was provided; each subject was inter-viewed and asked about any fall in the previous 6 months and his or her replies were checked off against the medical record kept at the residential home. Each subject's body mass index (BMI) of both the reliability and inter-group comparison study was calculated, as body weight (0.1 kg accuracy) divided by height (0.01 m accuracy) squared. Body weight was measured while the individual was wearing sport clothes (no shoes) with a calibrated balance beam scale (Health-O-Meter Model 402EXP). Height was measured with a stadiometer (Seca 202). Each subject underwent the test under the same instructions and conditions.

2.1.2. Inter-group comparison study

Sixty non-institutionalized subjects volunteered to take part in the inter-group comparison study (9 men, 51 women; 74.2 ± 4.9 years; 1.55 ± 0.07 m; 68.8 ± 9.5 kg) (80% statistical power of detecting differences between the groups, at a $p < 0.05$ level of significance). These subjects were recruited in three different primary healthcare centers and in two sport facilities, all located in Barcelona. No a priori rationale existed to expect an effect of gender on the outcome variables. Subjects were allocated to four groups: 15 sedentary subjects who had at least one fall in the previous 6 months (Group 1); 15 sedentary subjects with no previous history of falls (Group 2); 15 active subjects with a previous history of falls (Group 3); and 15 active subjects with no previous history of falls (Group 4). Physical activity level was assessed through a self-report, short version of the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003). Subjects were considered active if they were categorized as having moderate or high physical activity level based on the self-report questionnaire. Subjects were considered sedentary if they were categorized as having low physical activity level. In Group 1, 9 subjects (60%) reported 1 fall, and 6 subjects (40%) reported 2 falls. In Group 3, 12 subjects (80%) reported 1 fall, and 3 subjects (20%) reported 2. Out of the 39 falls recorded, 4 (10.3%) had medical consequences and required hospitalization. The same screening process used in the reliability study was used for the inter-group comparison study. All subjects' replies were checked off against their medical records kept at each healthcare center.

2.2. Study design

2.2.1. Reliability study

Ten subjects undertook the modified TGUG test twice within the same day, with a 40-min rest between the first and second trials to assess internal reliability between repeated trials within a day (Atkinson and Nevill, 1998). The rest period consisted of sitting down on a chair in a room adjacent to the test track. Inter-rater reliability was assessed with three investigators who timed both trials using a 10-lap memory stopwatch Decathlon Geonaute Trt'L 500 (1/100 s accuracy). The reproducibility of a qualitative evaluation of the trials was accomplished by the completion of an AQ at each trial by the three investigators. A different investigator was responsible for initiating each test. All trials were digitally recorded with the camera positioned in the frontal plane at a 2-m distance from the end of the testing track. The time from when the ball was kicked to when it passed the 8-m line was measured within 0.01 s using a Sony Digital video recorder, in order to provide agreement with the hand-timing. To control for circadian variation, each subject underwent the test at the same time each day.

2.2.2. Inter-group comparison study

Each subject performed the test only once, following a demonstration. The same investigator initiated the test, timed each subject with the same 10-lap memory stopwatch and completed the AQ.

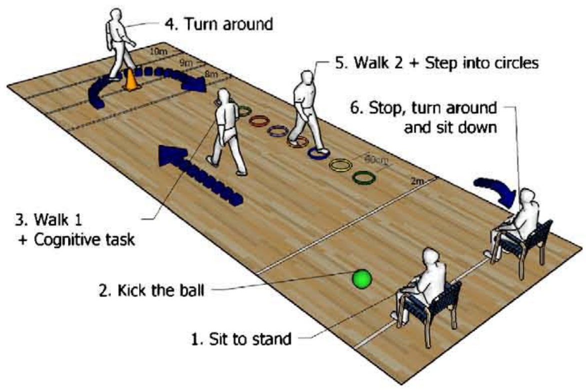


Fig. 1. Modified TGUG test achievement.

2.3. Specific methodology

The TGUG test was designed to assess balance and gait (Podsiadlo and Richardson, 1991). The modified TGUG test measures balance, gait and coordination with a cognitive and physical task while walking (counting backwards from 15 to 0 and stepping into circles) (Shumway-Cook et al., 2000), while lower extremity strength is measured by standing up from a chair (Campbell et al., 1989) and kicking as hard as possible a 19-cm diameter, 0.2 kg, soft sponge ball as a challenging task (Fig. 1). It has been previously demonstrated that challenging tasks are more suitable in assessing the risk of falling in the elderly (Lord et al., 2001). Control of balance in a narrow base stance (Melzer et al., 2004), such as stepping into circles, may also be an important tool in identifying elderly fallers.

The instructions given to perform the test were as follows: "Sit down with your back resting on the back of the chair and with your two arms resting on your legs. When you hear the word "go", stand up without using your arms, kick the ball in front of you as hard as you possibly can, using the instep of the foot you feel the safest. Then walk at your normal pace while counting backwards from 15 to 0 out loud. Turn around back the cone, without touching it, and go back to your seat, stepping into the circles, trying not to touch any of them. Finally, sit down again, trying not to use your arms".

The stopwatches were activated on the word "go" and the button that saved the time intervals was pressed also after the following stages: when the subject stood up and kicked the ball; when the ball passed the 8-m line; and when the subject returned to the seated position in the same chair (42 cm height from the seat to the ground). The TT needed to perform the test provided a quantitative evaluation of performance. A qualitative evaluation was performed by the completion of an AQ. This AQ assesses 6 items with a Likert scale from 0 to 3, where 0 is the equivalent to needing help in order to perform the task, and 3 is equivalent to performing the task unaided with no mistakes. The maximum points that can be attained are 18. The items assessed were: (1) standing up from the chair, (2) kicking the ball, (3) walking whilst counting backwards from 15 to 0, (4) walking around the cone, (5) walking whilst stepping into the circles, and (6) sitting back down again (Appendix A). To design the scoring options of the AQ, content and construct validity was established by 4 experts of The Geriatrics Committee of the National College of Physiotherapy of Catalonia, two physical therapists with 17 and 5 years clinical experience, one exercise physiologist with 9 years experience evaluating functional ability in elderly persons, and one geriatrician with 13 years clinical experience.

2.3.1. Statistical methods for the reliability protocol

The quantitative assessment of the reliability study was divided into three parts: (a) TT; (b) the time of the ball from when it was kicked to when it went past the 8-m line (BT); and finally, (c) the reliability of the AQ. The sample of the reliability study was homogenous. As discussed elsewhere (Atkinson and Nevill, 1998), reliability statistics used in the present study are unaffected by homogenous sample of individuals.

To assess the agreement between the three investigators (Inv. 1, Inv. 2 and Inv. 3) CR, ICC and limits of agreement were determined and plotted for the first and second trials separately. This approach was adopted for TT and BT (Fig. 2a and b) as correlation coefficients are unable to detect any random error or systematic bias to the data (Atkinson and Nevill, 1998). Weighted Kappa K of Cohen was calculated only in the second trial to assess the agreement between the three investigators and the AQ. If the categories follow an ordinal scale the weighted Kappa K of Cohen is the appropriate measurement for the assessment of reliability (Szklo and Nieto, 2003). Cronbach's alpha was performed to determine internal consistency across the six items assessed in the AQ.

2.3.2. Statistical methods for the inter-group comparison study

Descriptive statistics (mean $\pm$ S.D.) were used to summarize the data. Prior to all the analyses, normality of the data was assessed by the one-sample Kolmogorov–Smirnov test for the data obtained in the TT and the AQ of the four intervention groups (Group 1–4). A one-

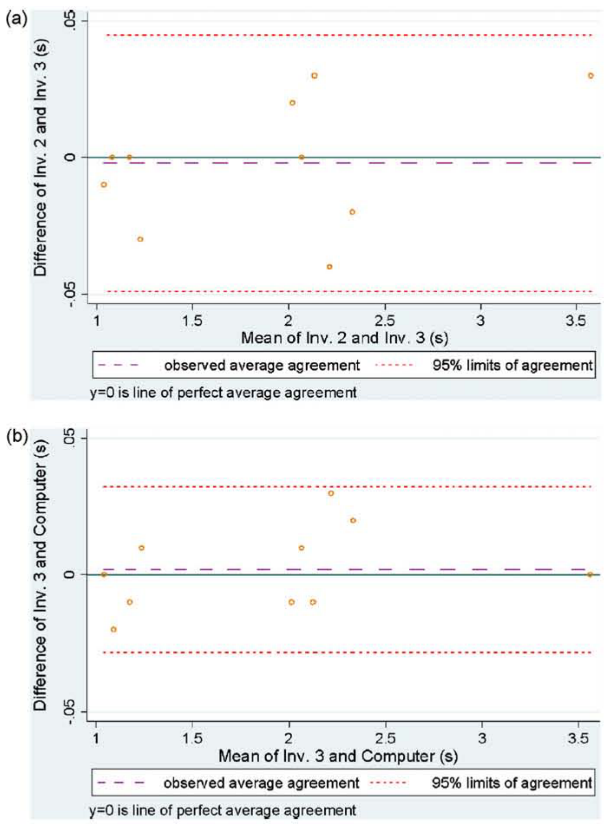


Fig. 2. (a) Limits of agreement (Bland–Altman plot) between investigator (inv.) 2 and inv. 3 in TT (s) (95% CI). (b) Limits of agreement (Bland–Altman plot) between inv. 3 and the comp. in BT (s) (95% CI).

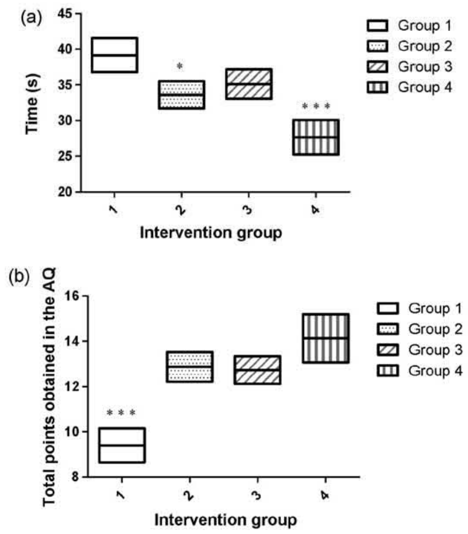


Fig. 3. (a) Mean ± 95% CI for TT for each group. TT in seconds to complete the modified TGUG test. Group 1 = 15 sedentary subjects with a previous history of falls in the last 6 months. Group 2 = 15 sedentary subjects with no previous history of falls in the last 6 months. Group 3 = 15 active subjects with a previous history of falls in the last 6 months. Group 4 = 15 active subjects with no previous history of falls in the last 6 months. *Significant difference between Groups 1 and 2. ***Significant difference between Group 4 and Groups 1–3. (b) Mean ± 95% CI of the AQ. AQ = total points obtained in the AQ. Group 1 = 15 sedentary subjects with a previous history of falls in the last 6 months. Group 2 = 15 sedentary subjects with no previous history of falls in the last 6 months. Group 3 = 15 active subjects with a previous history of falls in the last 6 months. Group 4 = 15 active subjects with no previous history of falls in the last 6 months. ***Significant difference between Group 1 and Groups 2–4.

way analyses of variance (ANOVA) was used to identify between group differences for TT and AQ. If a significant inter-group difference was identified, Bonferroni-corrected unpaired *t*-tests were performed to identify the precise location of the inter-group differences. The mean ± 95% confidence interval data (CI) was plotted for each group and for each dependent variable (TT and AQ) (Fig. 3a and b). Effect size (Cohen's *d*) was also calculated to indicate the magnitude of any group differences. To assess the association between the TT and the four intervention groups a multiple linear regression analysis was performed. A similar approach was used for AQ. Both models were co-varied for age, gender and BMI variables. Dummy variables were created for the four intervention group variables in both models, using Group 1 as the baseline. The coefficient of determination values (R^2) were also calculated for both models.

For the statistical analyses, SPSS version 14.0 and STATA version 9.1 were used, and a significance level of 0.05 was selected.

3. Results

3.1. The reliability study

3.1.1. TT time

To assess the agreement between the three investigators, CR, ICC and limits of agreement were calculated in the first and second trials separately, using the overall TT. CR values for the TT were above 98% and with ICC of TT = 0.999. The differences in TT between the three investigators' measures ranged from 0.19–0.55 s (S.D. of the mean difference). Limits of agreement of all combinations between the three investigators' measures were plotted (e.g., Fig. 2a). In all cases (Inv. 1–Inv.2, Inv. 2–Inv. 3, and Inv. 1–Inv. 3), all values fell within ±2*x* S.D. of the mean difference.

3.1.2. The BT

Each of the three investigators measured the time elapsed between when the subject kicked the ball to when the ball passed the 8-m line, this time was also derived from the digital recording (comp.). CR, ICC and limits of agreement were calculated in the first and second trials separately. CR values for the BT were above 96% and with ICC of BT = 0.983. The differences in BT between the three investigators' measures ranged from 0.012 to 0.20 s of the S.D. of the mean difference. Limits of agreement of all combinations between the three investigators' measures and the comp. were plotted (e.g., Fig. 2b). In all cases (Inv. 1–comp., Inv. 2–comp., and Inv. 3–comp.) all values were within ±2*x* S.D. of the mean difference.

3.1.3. Reliability of the AQ

The three investigators completed a 6-item AQ, with a 0–3 Likert scale. The weighted Kappa K of Cohen was calculated only in the second trial to assess the agreement between the three investigators. The weighted Kappa K of Cohen demonstrated high inter-tester reliability (Inv. 1–2 = 0.976; Inv. 1–3 = 0.858; Inv. 2–3 = 0.835). The ICC of AQ = 0.954, and Cronbach's alpha across items was 0.868.

3.2. Inter-group comparison study

The one-way ANOVA demonstrated significant differences ($p < 0.05$) between both the mean scores of TT in the four intervention groups. Furthermore, there were also significant differences ($p < 0.05$) between the points obtained in the AQ in the four groups. Table 1 illustrates the mean and 95% CI of both dependent variables (TT and AQ). With respect to the TT scores, significant differences ($p < 0.05$) were noted between the mean score for Group 4 and the rest of the groups, and between Groups 2 and 1. Between Groups 2 and 3 no significant differences were noted (Group 1 = 39.19 ± 4.28 s; Group 2 = 33.61 ± 3.46 s; Group 3 = 35.10 ± 3.73 s; Group 4 = 27.65 ± 4.41 s) (Fig. 3a). With respect to the AQ scores, significant differences ($p < 0.05$) were noted between the mean score for Group 1 and the rest of the groups. No significant differences were noted between the other three groups (Group 1 = 9.40 ± 1.35 points; Group 2 = 12.87 ± 1.19 points; Group 3: 12.73 ± 1.10 points; Group 4: 14.13 ± 1.92 points) (Fig. 3b). Cohen's *d* demonstrated a large effect size (>0.8) when differences between the group mean scores were significant.

The multiple linear regression model that was used was dependent variables (TT and AQ) = $\beta_0 + \beta_1 \cdot$gender + $\beta_2 \cdot$age + $\beta_3 \cdot$Group 2 + $\beta_4 \cdot$Group 3 + $\beta_5 \cdot$Group 4 + E. β coefficients are shown in Table 2. BMI made no significant contribution in the data. As shown in Table 2, after the multiple linear regression model for TT was co-varied with the gender and age variables, Group 2 showed a drop of 5.68 s with respect to the baseline (Group 1) (95% CI = −3.41 and −7.94); Group 3 showed a decrease of 5.89 s with respect to the baseline (95% CI = −8.27 and −3.52); and Group 4 a decrease of 11.18 s with respect to the baseline (95% CI = −13.48 and −8.89). We had an $R^2 = 0.43$ with the BMI variable, while the final model displayed an $R^2 = 0.63$.

With respect to the AQ scores, BMI and gender made no significant contribution in the data. After the multiple linear regression model for the AQ was co-varied with the age variable, Group 2 showed an increase of 3.39 points with respect to the baseline (95% CI = 2.38–4.40) over the total points obtained in the AQ; Group 3 an increase of 3.46 points with respect to the baseline (5% CI = 43–49); and Group 4 an increase of 4.59 points with respect to the baseline (95% CI = 3.56–5.62). $R^2 = 0.34$ was with the BMI variable, with the gender variable it was $R^2 = 0.49$, while in the final model we obtained $R^2 = 0.53$.

Table 1
Results regarding the intervention groups for the dependent variables.

	TT (s)		AQ	
	Mean	95% CI	Mean	95% CI
Group 1	39.19	36.82–41.55	9.40	8.65–10.15
Group 2	33.61	31.69–35.53	12.87	12.21–13.52
Group 3	35.10	33.04–37.17	12.73	12.12–13.34
Group 4	27.65	25.21–30.10	14.13	13.07–15.20

Table 2
β-Coefficients and R^2 values of the multiple linear regression models, 95% CI.

	TT (s)		AQ	
	β	95% CI	β	95% CI
Constant	25.87	(13.30, 38.43)	9.25	(8.52, 9.97)
Gender	−4.87	(−7.22, −2.52)	1.15	(0.09, 2.22)
Age	0.19	(0.02, 0.37)	–	–
Group 2	−5.68[a]	(−7.94, −3.41)	3.39[a]	(2.38, 4.40)
Group 3	−5.89[a]	(−8.27, −3.52)	3.46[a]	(2.43, 4.49)
Group 4	−11.18[a]	(−13.48, −8.89)	4.59[a]	(3.56, 5.62)
R^2 value		0.63		0.53

[a] Values with respect to the baseline (Group 1 = 15 sedentary subjects with a previous history of falls in the last 6 months).

4. Discussion

Based on the evidence from the present study, it can be stated that the modified TGUG test demonstrated good sensitivity and good inter-tester reliability from both a quantitative and qualitative perspective. Fall risk assessment is not standardized within or across hospital, nursing home, or community-dwelling settings. Previous evaluations have used functional assessment instruments such as the Berg Balance Test (Berg et al., 1992), Dynamic Gait Index (Whitney et al., 2000), TGUG (Podsiadlo and Richardson, 1991), or Tinetti Performance Mobility Assessment (Tinetti, 1986). Typically, these instruments do not assess intrinsic factors related to falls other than gait and balance, although all provide standardized measures of disability and functional limitations. Data on inter-rater reliability had been provided for three of the functional assessment tools mentioned above, and ranged from 58% to 98% across the various functional assessment tools. Information on predictive validity had been included for the four functional assessment studies (Tinetti, 1986; Berg et al., 1992; Whitney et al., 2000). An operational definition to identify a threshold or cut-off score above which the patient would be described as being at high risk had been provided for the four tests, as well as reported sensitivity and specificity. The median sensitivity scores were 85% and the median specificity scores were 78%. Despite the good inter-rater reliability and predictive validity, the majority of these tests were developed mainly in hospital or nursing home settings. Taking into account that there are few tests that have been found to be strongly predictive of falls amongst active senior citizens who live independently, the modified TGUG test was a modified form of the TGUG test (Podsiadlo and Richardson, 1991) to assess the four main risk factors associated with the risk of falling amongst people over the age of 65: (a) strength in lower extremities, (b) coordination, (c) balance and (d) gait, adding challenging tasks to predict fall risk in an active, non-institutionalized elderly population.

The modified TGUG test contains an attention component. Thus, it differs from the response to perturbation models often used to assess balance control in older people (Maki et al., 1990, 1994). Although these tests have revealed significant age-related differences, they have not been found to be strong predictors of falls. Two studies found that simple measures of unperturbed sway are better able to distinguish fallers from non-fallers than measures of response to perturbation (Maki et al., 1990, 1994).

Some studies have found that asking older people to count backwards or answer a question can impair balance and gait (Shumway-Cook et al., 2000). Thus, even standing requires cognitive input in older people with balance disorders, and, as balance tasks become more challenging, the attention requirements increase correspondingly (Brown et al., 1995). It has been demonstrated that challenging tasks, such as kicking a soft ball included in the modified TGUG test, are a better determinant of the risk of falling in the elderly (Lord et al., 2001). Moreover, this action required balancing with one leg while kicking a ball, and one-leg balance appears to be a significant predictor of falls (Vellas et al., 1997; Menéndez-Colino et al., 2005). Control of balance in narrow base stance (Melzer et al., 2004) such as stepping into circles also included in our test, may also be an important tool in identifying elderly fallers.

Subjects of the inter-group comparison study were categorized into sedentary or active regarding their physical activity level, assessed through self-report, short version of the IPAQ (Craig et al., 2003). It has been previously demonstrated that a self-administered physical activity questionnaire can satisfactorily estimate the physical activity level of an elderly population compared to both a 7-day activity record follow-up (Wolf et al., 1994; Norman et al., 2001), and a single 24-h accelerometer score (Pols et al., 1996). The estimates obtained by the IPAQ have been demonstrated to be sensitive enough, in relative terms, to discriminate between physical activity levels in an elderly population (Kriska and Caspersen, 1997).

The most appropriate method of examining reproducibility is to take repeated measurements on a series of subjects and to examine the degree to which values vary for individuals. Although correlation coefficients give information about the degree of association between two sets of data, or the consistency of position within two distributions, and are frequently applied to reliability studies, Atkinson and Nevill (1998) discussed the limitations of these methods. The use of CR, ICC and limits of agreement was an attempt to overcome some of the limitations of the classic correlation coefficients and evaluate the systematic bias and random error within the data (Atkinson and Nevill, 1998). Scrutiny of the plots presented in Fig. 2a and b indicated no evidence of any learning effect (systematic bias) and minimal random error for TT and BT and the three investigators' measures.

Based on the data from the one-way ANOVA, no significant differences were noted between Groups 2 and 3 neither for TT nor AQ. Therefore, it appears that being active conferred no significant advantage to the individual, if that individual had a previous history of falls. It has been largely discussed that a previous history of falls usually results in a psychological effect named fear of falling, leading to reduced daily activities (Tinetti et al., 1990) and patient's loss of confidence in his or her balance abilities (Powell and Myers, 1995), with subsequent losses in physical capabilities. The test appeared to have good discriminating powers with respect to TT, as differences were evident between Groups 1 and 2 and between Group 4 and the other groups. AQ did not demonstrate the same sensitivity as TT, AQ was only capable of discriminating between individuals of very low function (Group 1) and the other groups. Considering the number of elderly individuals in the general population that lay in Groups 2–4, the utility of the AQ test needs to be challenged. Prevention intervention might be then needed in reducing the risk of falling.

Multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable, by fitting a linear equation to observed data (Szklo and Nieto, 2003). The appropriate approach is to adjust the multiple linear regression model when the variation (increment or decrement) between the regression coefficient with and without those specific modifying variables, shows a significant effect (Rothman and Ericson, 1987; Doménech, 2006). Three co-varied variables were introduced into the model (age, gender and BMI), but our results indicated that only age and gender showed significant effects using TT as the dependent variable ($R^2 = 63\%$), thus age and gender modified the TGUG test. Previous studies had demonstrated that with increased age the risk of falling is higher (American Geriatrics Society et al., 2001; Perell et al., 2001; Melzer et al., 2004; Royal College of Nursing, 2004); in our study, as age increased, TT measures also increased. Analysis of the TT by gender reveals that males need a shorter time to finish the test than females. A prospective study undertaken in a community setting found a 35% fall incidence rate in 1 year follow-up, with no significant differences between women and men fall rates (Campbell et al., 1989). Another study showed that falling rates were higher in older women than in older men (Lord et al., 2001). Evidence from the present study appears to support this latter finding. However, regression analysis demonstrates that differences in age rather than gender contribute to the reduced time observed in younger subjects. In fact, when controlling for BMI, subjects with a higher BMI appear to have a higher but not significantly different TT than subjects with a lower BMI. Perhaps this suggests a BMI effect, but the BMI effect appears marginal compared to age and gender.

With respect to the AQ as the dependent variable, only the age variable showed a significant effect ($R^2 = 53\%$). Analysis of the AQ by age reveals that as age increased, the total points obtained with the AQ decreased. BMI and gender made no significant contribution in the data. Based on these findings, age and gender should be taken into account when developing these predictive equations with older adult populations (Katsiaras et al., 2005).

There are some limitations with this study. Despite the fact that good agreement between investigators was obtained, in order to make the study design more precise, photoelectric cell measurements could have been used to capture the time data. Moreover, dual-energy X-ray absorptiometry (DEXA) could also have given more precise data with respect to the assessment of body fat. The unbalanced cell numbers may have influenced the inter-group comparisons.

5. Conclusion

The implications of the findings from this study suggest that the modified TGUG test for TT (*s*) may be suitable to discriminate older individuals of high and low functional levels.

Conflict of interest statement

None.

Acknowledgements

Special thanks to the staff and participants of Europolis, Esports 3, and the three primary healthcare centers of the Institut Català de la Salut, all of them located in Barcelona. We would like to thank the Facultat de Psicologia, Ciències de l'Educació i l'Esport Blanquerna for its collaboration. We also thank Dr. Todd M. Manini for his valuable comments on the manuscript.

Appendix A. AQ of the modified TGUG test

1. Sit to stand	3 able to stand up without using hands in a steady and controlled action
	2 able to stand up using hands in a steady and controlled action
	1 able to stand up using hands after multiple attempts
	0 needs or asks for help
2. Kick ball	3 able to kick ball without losing balance
	2 able to kick ball but needs to take a step to get back on balance
	1 able to kick ball with difficulty finding balance
	0 needs or asks for help
3. Walk whilst counting backwards from 15 to 0	3 able to coordinate walking with counting without making a mistake
	2 able to coordinate walking with counting with one mistake
	1 poor coordination between walking and counting with more than one mistake
	0 needs help or cannot perform the counting task
4. Go around back of cone	3 able to go around the cone without touching it, without going outside the marked area, and keeping up the pace
	2 able to go around the cone without touching it, without going outside the marked area, but slowing down the pace
	1 able to go around with obvious signs of insecurity
	0 needs or asks for help

5. Step into circles	3 able to walk, stepping one foot into each circle without touching them and without losing balance
	2 able to walk, stepping one foot into each circle, touching one or needing to take an extra step outside the rings to regain balance
	1 able to walk stepping one foot in each circle, touching more than one, or needing more than one extra step to regain balance
	0 needs or asks for help
6. Sit back down	3 able to sit down smoothly without using hands
	2 able to sit down sharply without using hands
	1 able to sit down using hands
	0 needs or asks for help

References

Abrams, W.B., Berkow, R., 1990. El Manual Merck de Geriatría. Doyma, Madrid.
American Geriatrics Society American Geriatrics Society, British Geriatrics Society, American Academy of Orthopaedic Surgeons Panel on Falls Prevention, 2001. Guidelines for the prevention of falls in older persons. J. Am. Geriatr. Soc. 49, 664–672.
Atkinson, G., Nevill, A.M., 1998. Statistical methods for assessing measurements error (reliability) in sports medicine. Sports Med. 26, 217–238.
Berg, K., Wood-Dauphinee, S., Williams, J.I., Maki, B., 1992. Measuring balance in the elderly: validation of an instrument. Can. J. Public Health 83, S7–S11.
Boulgarides, L.K., McGinty, S.M., Willett, J.A., Barnes, C.W., 2003. Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. Phys. Ther. 83, 328–339.
Brown, A.P., 1999. Reducing falls in elderly people: a review of exercise interventions. Physiother. Theory Pract. 15, 56–68.
Brown, L.A., Shumway-Cook, A., Woollacott, M.H., 1995. Attentional demands and postural recovery: the effects of aging. J. Gerontol. A: Biol. Sci. Med. Sci. 54, M165–M171.
Campbell, A.J., Borrie, M.J., Spears, G.F., 1989. Risk factors for falls in a community-based prospective study of people 70 years and older. J. Gerontol. A: Biol. Sci. Med. Sci. 44, M112–M117.
Ciccarelli, J., 2006. Generalitat de Catalunya. Departament de Sanitat (online). Available at: www.prodig.yweb.net/rol. Accessed September 19, 2006.
Craig, C.L., Marshall, A., Sjöström, M., Bauman, A.E., Booth, M.L., Ainsworth, B.E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J.F., Oja, P., 2003. International Physical Activity Questionnaire: 12 country reliability and validity. Med. Sci. Sports Exerc. 35, 1381–1395., In: www.ipaq.ki.se.
Doménech, J.M., 2006. Fundamentos de Diseño y Estadística. Correlación y Regresión lineal, first ed. Signo, Barcelona, 71–76 (in Spanish).
Katsiaras, A., Newman, A.B., Kriska, A., Brach, J., Krishnaswami, S., Feingold, E., Kritchevsky, S.B., Li, R., Harris, T.B., Schwartz, A., Goodpaster, B.H., 2005. Skeletal muscle fatigue, strength, and quality in the elderly: the Health ABC study. J. Appl. Physiol. 99, 210–216.
Kriska, A.M., Caspersen, C.J., 1997. Introduction To A Collection Of Physical Activity Questionnaires. Med. Sci. Sports Exerc. 29, 5–9.
Lord, S.R., Sherrington, C., Menz, H., 2001. Falls in Older People: Risk Factors and Strategies for Prevention, first ed. Cambridge University Press, Cambridge.
Maki, B.E., Holliday, P.J., Fernie, G.R., 1990. Aging and postural control: a comparison of spontaneous – and induced – sway balance tests. J. Am. Geriatr. Soc. 38, 1–9.
Maki, B.E., Holliday, P.J., Topper, A.K., 1994. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. J. Gerontol. A: Biol. Sci. Med. Sci. 49, M72–M84.
Mathias, S., Nayak, U., Isaacs, B., 1986. Balance in elderly patients: the "Get Up and Go" test. Arch. Phys. Med. Rehabil. 67, 387–389.
Melzer, I., Benjuya, N., Kaplanski, J., 2004. Postural stability in the elderly: a comparison between fallers and non-fallers. Age Aging 33, 602–607.
Menéndez-Colino, R., Sánchez, C., De Tena, A., Lázaro, M., Cuesta, F., Ribera, J.M., 2005. Utilidad de la estación unipodal en la valoración del riesgo de caídas. Rev. Esp. Geriatr. Gerontol. 40, 18–23 (in Spanish).
Nevitt, M.C., Cummings, S.R., Kidd, S., Black, D., 1989. Risks factors for recurrent nonsyncopal falls: a prospective study. J. Am. Med. Assoc. 261, 2663–2668.
Norman, A., Bellocco, R., Bergström, A., Wolk, A., 2001. Validity and reproducibility of self-reported total physical activity-differences by relative weight. Int. J. Obes. 25, 682–688.
Perell, K.L., Nelson, A., Goldman, R.L., Luther, S.L., Prieto-Lewis, N., Rubenstein, L.Z., 2001. Fall risk assessment measures: an analytic review. J. Gerontol. A: Biol. Sci. Med. Sci. 56, M761–M766.
Podsiadlo, D., Richardson, S., 1991. The timed "Up and Go": a test of basic functional mobility for frail elderly persons. J. Am. Geriatr. Soc. 39, 142–148.
Pols, M.A., Peeters, P.H., Kemper, H.C., Collette, H.J., 1996. Repeatability and Relative Validity of Two Physical Activity Questionnaires in elderly women. Med. Sci. Sports Exerc. 28, 1020–1025.
Powell, L.E., Myers, A.M., 1995. The activities-specific balance confidence (ABC) scale. J. Gerontol. A: Biol. Sci. Med. Sci. 50, M28–M34.
Reuben, D.B., Herr, K., Pacala, J.P., Potter, J.F., 2002. Geriatrics at your fingertips. Med. Trends Am. Geriatr. Soc.
Rothman, E.D., Ericson, W.A., 1987. Statistics: Methods and Applications. Kendall/Hunt Publishing Co., Iowa, 203 p.
Royal College of Nursing, 2004. Clinical practice guideline for the assessment and prevention of falls in older people. In: Feder, G. (Ed.), Guideline Commissioned by the National Institute for Clinical Excellence, Royal College of Nursing, London, pp. 16–28.
Shumway-Cook, A., Brauer, S., Woollacott, M., 2000. Predicting the probability for falls in community-dwelling older adults using the timed up and go test. Phys. Ther. 80, 896–903.
Szklo, M., Nieto, J., 2003. Epidemiología intermedia. Conceptos y aplicaciones. Díaz de Santos, Madrid, pp. 397–399 (in Spanish).
Tinetti, M.E., 1986. Performance-oriented assessment of mobility problems in elderly patients. J. Am. Geriatr. Soc. 34, 119–126.
Tinetti, M.E., 2003. Preventing falls in elderly persons. N. Engl. J. Med. 348, 42–49.
Tinetti, M.E., Richman, D., Powell, L., 1990. Falls efficacy as a measure of fear of falling. J. Gerontol. B: Psychol. Sci. Soc. Sci. 45, P239–P243.
Vellas, B.J., Wayne, S.J., Romero, L.R., Baumgartner, N.R., Rubenstein, L.Z., Garry, P.J., 1997. One leg balance is an important predictor of injurious falls in older persons. J. Am. Geriatr. Soc. 45, 735–738.
Whitney, S.L., Hudak, M.T., Marchetti, G.F., 2000. The dynamic gait index relates to self-reported fall history in individuals with vestibular dysfunction. J. Vestib. Res. 10, 99–105.
Wolf, A.M., Hunter, D.J., Colditz, G.A., Manson, J.E., Stampfer, M.J., Corsano, K.A., Rosner, B., Kriska, A., Willett, W.C., 1994. Reproducibility and validity of a self-administered Physical Activity Questionnaire. Int. J. Epidemiol. 23, 991–999.

4.2 Publication two

Giné-Garriga M, Guerra M, Manini TM, Marí-Dell'Olmo M, Pagès E, Unnithan VB. Measuring Balance, Lower Extremity Strength and Gait in the Elderly: Construct Validation of an Instrument. *Archives of Gerontology and Geriatrics* [In press].

Archives of Gerontology and Geriatrics xxx (2009) xxx–xxx

Contents lists available at ScienceDirect

Archives of Gerontology and Geriatrics

journal homepage: www.elsevier.com/locate/archger

Measuring balance, lower extremity strength and gait in the elderly: Construct validation of an instrument

Maria Giné-Garriga [a,b], Míriam Guerra [a], Todd M. Manini [c], Marc Marí-Dell'Olmo [d], Esther Pagès [e], Viswanath B. Unnithan [f,*]

[a] FPCEE Blanquerna, Universitat Ramon Llull, Department of Physical Activity and Sport Sciences, Císter 34, 08022 Barcelona, Spain
[b] Primary Health Care of Barcelona, Department of Physical Activity and Health, Institut Català de la Salut, Esteve Terrades 30, 08023 Barcelona, Spain
[c] University of Florida, Department of Aging and Geriatric Research, Institute on Aging, Gainesville, FL 32611, USA
[d] CIBER of Epidemiology and Public Health (CIBERESP), Agència de Salut Pública, Plaça Lesseps 1, 08023 Barcelona, Spain
[e] Hospital Vall d'Hebron, Department of Physical Medicine and Rehabilitation, Passeig Vall d'Hebron 119-129, 08035 Barcelona, Spain
[f] Sport Department, Deanery of Sciences and Social Sciences, Liverpool Hope University, Hope Park, Liverpool L16 9JD, UK

ARTICLE INFO

Article history:
Received 16 June 2009
Received in revised form 3 October 2009
Accepted 6 October 2009

Keywords:
Geriatric assessment
Posture
Muscle strength
Gait in aging

ABSTRACT

The purpose of the study was to determine the degree to which scores of a modified version of the 'Timed Get Up and Go' test (TGUG) were associated with other measures of functional performance. Thirty-seven community-dwelling older women (72.3 ± 5.5 years) volunteered to participate. Subjects were assessed when performing the modified TGUG test. Correlations between the performance-oriented mobility assessment (POMA), single-leg balance, five chair rises, fast and normal gait speed, knee extension and flexion strength, and the modified TGUG were conducted. Total time to perform the modified TGUG test was significantly correlated with normal and fast gait speed ($p < 0.05$). The Pearson correlation coefficients were 0.841 and 0.748, respectively. The time needed to perform several tasks of the modified TGUG test significantly correlated with five chair rises, and with right knee extensor strength ($p < 0.05$). Points obtained in the assessment questionnaire correlated significantly to points obtained in the POMA scale ($p < 0.05$). The Pearson correlation coefficient was 0.795. Based on the strength of the correlations obtained between components of the modified TGUG and the comparison tests, concurrent, criterion validity of the modified TGUG has been established.

1. Introduction

The normal aging process is characterized by muscle fiber atrophy and reduction in skeletal muscle mass (Katsiaras et al., 2005), which is generally associated with muscle weakness (Katsiaras et al., 2005; Aagaard et al., 2007). The peripheral sensory systems that are responsible for maintaining posture control also deteriorate with aging (Tinetti et al., 1988; Daubney and Culham, 1999; Fried et al., 2000), and the ability to maintain control of posture is important for the successful performance of most daily activities (Daubney and Culham, 1999).

Tinetti et al. (1995) demonstrated that risk factors for falls such as muscle weakness, impaired balance and reduced mobility, might also be risk factors for functional dependence. Current guidelines (American Geriatrics Society, 2001) suggest that community-dwelling older persons should be given a short screen for diminished physical functioning.

There is evidence to suggest that sedentary, community-dwelling elderly patients with a previous history of falls, thus individuals who are at a greater risk of becoming functionally dependent, are over-using the resources at primary care centers and increasing consultation rates of our health services (Ortega et al., 2004). Consequently, an ability to identify their decline in function with a short and easy assessment field test is needed in order to target those high-risk individuals for preventive intervention.

In clinical practice, performance-oriented functional tests are widely adopted in evaluating the mobility and balance impairments in the elderly population. Tasks such as transfer in and out of a chair, a 3-m walk, turning, standing with eyes closed, and picking up an object from the floor, are some of the tasks included in the three most commonly used tests, TGUG (Podsiadlo and Richardson, 1991; Bischoff et al., 2003), the Berg Balance Scale (BBS) (Berg et al., 1992; Chiu et al., 2003), and the POMA (Tinetti, 1986). These tests do not include, however, more challenging mobility efforts of everyday life such as walking while talking, walking while performing another physical task, one-leg stance with an added physical task, as well as avoiding obstacles.

* Corresponding author. Tel.: +44 0151 291 2045; fax: +44 0151 291 3414.
E-mail address: unnithv@hope.ac.uk (V.B. Unnithan).

0167-4943/$ – see front matter © 2009 Published by Elsevier Ireland Ltd.
doi:10.1016/j.archger.2009.10.008

The ability to execute and maintain gait while performing simultaneous cognitive, verbal, or motor tasks (dual-task) has been well-documented to result in cognitive or motoric interference that results in diminished gait performance, and impaired secondary task performance (Armieri et al., 2009). With normal aging, structural changes of the brain occur, especially in the prefrontal areas, regions that have been associated with the executive function and attentional systems (Charlton et al., 2006). Attentional resources are limited in capacity, and so the performance of two attention-demanding tasks will cause deterioration of at least one of the tasks. Woollacott and Shumway-Cook (2002) demonstrated that the performance of cognitive tasks while walking increased the reaction times of the cognitive task or reduced gait speed.

None of the previously mentioned tests above assess the capacity of dual-tasks. Consequently, there is a need to establish the criterion validity of the dual-task component in the modified TGUG, as walking while performing a simultaneous task mimics the physical processes that are encountered in a normal day.

The modified TGUG has been developed as a physical function assessment tool to identify older people with impairments in one or more of the physiological domains that have a substantial effect on the ability of older persons to remain independent: muscular weakness, and deficits in gait and balance. It has been previously demonstrated, that this test: (a) provides reliable measurements (Giné-Garriga et al., 2009), (b) is simple to administer, (c) needs a short administration time, (d) is feasible for older people to undertake in community settings, and (e) is capable of providing quantitative measurements. Furthermore, the test contains the ability to dual-task, thus, it contains many of the measures required for safe mobility in one single test.

The purpose of the current study was to establish the validity of a modified version of the TGUG test. Specifically, the objective was to determine the degree to which scores of the modified TGUG test correlated with other measures typically used in the literature to document the age-related decline in function (concurrent criterion validity).

2. Subjects and methods

2.1. Subjects

Forty-two elderly women volunteered to take part in the study and thirty-seven completed the testing protocol (72.3 ± 5.5 years, 154.4 ± 4.7 m, 71.2 ± 8.3 kg). Four women did not complete the testing due to the loss of interest in the study, and one had a knee surgery before ending the testing period. The sample size was chosen expecting correlations higher than 0.45 from our predictors, with a statistical power of 80%, at a 0.05 level of significance. Our predictors were: (1) SU (the time needed to stand up from a chair without using their arms and kick the ball) and BT (the time elapsed between when the subject kicked the ball to when the ball passed the 8 m line) as lower extremity strength independent variable; (2) kick 8 m line (the time elapsed between when the subject kicked the ball and walked pass the 8 m line while performing a cognitive task such as counting backwards) and TT-kick 8 m (the time from when the subject crossed the 8m line and returned to the chair while performing a physical task such as stepping into circles) as dual-task independent variable; (3) TT (the total time needed to perform the test); and (4) AQ (the assessment questionnaire). Characteristics of the subjects are shown in Table 1. Volunteers were recruited from 9 primary healthcare centers. Inclusion criteria were: (a) women being 65 years of age or older, (b) non-institutionalized, (c) with a low physical activity level assessed through the self-report short version of the international physical activity questionnaire (IPAQ) (Craig et al., 2003), and (d) with at least two falls reported in the 12-month period prior to the date of recruitment. A fall was defined as any disturbance of balance during routine activities that resulted in an unintentionally coming to rest on the ground or lower level with or without loss of consciousness (Reuben et al., 2002).

Written informed consent was obtained from all subjects, and a local university ethics committee gave approval for the study. Each subject underwent the testing under the same instructions and conditions.

Table 1
Characteristics of the subject population and scores of the comparison tests.

Characteristics	Mean ± SD	Proportion, *n* (%)
Age (years)	72.3 ± 5.5	
Anthropometrics		
Height (cm)	154.4 ± 4.7	
Weight (kg)	71.2 ± 8.3	
BMI (kg/m^2)	30.0 ± 3.8	
Marital status		
Married, partner alive		9 (24.3)
Single, never married		3 (8.1)
Widowed		22 (59.5)
Divorced		3 (8.1)
SF-12 (units)		
SF-12 PF	39.8 ± 9.5	
SF-12 PCS	35.5 ± 7.9	
SF-12 MCS	33.6 ± 9.6	
Medical conditions		
Depression (Yesavage Depression Scale > 5)	11 (29.7)	
Poor balance (near-tandem stance < 30 s)	28 (75.7)	
Stroke		6 (16.2)
High blood pressure		19 (51.4)
Arthritis		4 (10.8)
Diabetes mellitus		5 (13.5)
Medication use		
Total number of medications	4.8 ± 2.4	
Benzodiazepine-use		9 (24.3)
Modified TGUG		
TT (s)	40.82 ± 8.19	
SU (s)	2.90 ± 0.99	
BT (s)	3.86 ± 2.06	
Kick-8 m (s)	15.98 ± 5.28	
TT-kick 8 m	24.83 ± 3.80	
AQ (points)	8.68 ± 2.29	
Comparison tests		
Gait speed		
Normal (m/s)	0.96 ± 0.12	
Fast (m/s)	1.19 ± 0.16	
Five chair rises (s)	18.57 ± 5.47	
Single-leg balance[a] (s)	6.57 ± 5.12	
POMA (points)	17.24 ± 3.37	
Isometric dynamometry[b]		
RKEMVC/bw (Nm/kg)	0.81 ± 0.29	
LKEMVC/bw (Nm/kg)	0.77 ± 0.19	
RKFMVC/bw (Nm/kg)	0.48 ± 0.20	
LKFMVC/bw (Nm/kg)	0.49 ± 0.20	

Notes: PF, physical function; PCS, physical composite score; MCS, Mental composite score; RKEMVC/bw, right knee extensor maximal voluntary isometric contraction divided by body weight; RKFMVC/bw, right knee flexor maximal voluntary isometric contraction divided by body weight.
[a] Sum of two trials.
[b] Highest value of two trials used for data analysis.

2.2. Study design

2.2.1. Measurements

One investigator was responsible for obtaining all outcome measurements. To provide reassurance, an assistant was always present during testing. In the recruitment process, the IPAQ was

Please cite this article in press as: Giné-Garriga, M., et al., Measuring balance, lower extremity strength and gait in the elderly: Construct validation of an instrument. Arch. Gerontol. Geriatr. (2009), doi:10.1016/j.archger.2009.10.008

used as a screening test to assess whether each subjects' physical activity level fit into the inclusion criteria of the present study (Craig et al., 2003). At the first visit, subjects underwent several tests to characterize the subject population and its results were used as descriptive indicators: (a) self-reported physical function, physical composite score and mental composite score via the SF-12 version 2 survey (Ware et al., 1996); (b) self-reported depression status assessed with Yesavage scale (Yesavage et al., 1983); and (c) the near-tandem stance balance time (Lord et al., 1999) (Table 1). At a second visit each subject underwent: (a) the modified version of the TGUG test (Fig. 1) (Giné-Garriga et al., 2009); (b) the comparison field tests mentioned below; and (c) the knee extensor and flexor strength. A 10-lap memory stopwatch (1/100 s accuracy) was used for the field testing.

The modified TGUG test is a physical function assessment tool that measures balance and gait with a dual-task: performing a cognitive (counting backwards from 15 to 0) and a physical task (stepping into circles) while walking; lower extremity strength is measured by standing up from a chair and kicking as hard as possible a 19 cm diameter, 0.2 kg, soft sponge ball as a challenging task (Fig. 1). The total time needed to perform the test (TT), the time needed to stand up from a chair (42 cm height from the seat to the ground) without using their arms and kick the ball (SU), the time elapsed between when the subject kicked the ball to when the ball passed the 8 m line (BT), the time elapsed between when the subject kicked the ball and walked pass the 8 m line (kick-8 m line), and the time from when the subject crossed the 8 m line and returned to the chair (TT-kick 8 m), provided quantitative evaluations of performance (the amount of space required is 10 m). A qualitative evaluation was performed by the completion of an assessment questionnaire (AQ). This AQ assesses 6 items with a Likert scale from 0 to 3, where 0 is the equivalent to needing help in order to perform the task, and 3 is equivalent to performing the task unaided with no mistakes. The maximum points that can be attained are 18. The instructions given to perform the test and the items assessed in the AQ were presented elsewhere (Giné-Garriga et al., 2009). As presented elsewhere (Giné-Garriga et al., 2009), coefficients of reliability (CR) for the TT were above 98%, and with intra-class correlation coefficients (ICC) of TT = 0.999. The differences in TT between the three investigators' measures ranged from 0.19 to 0.55 s SD of the mean difference. Weighted Kappa K of Cohen ranged 0.835–0.976, with ICC of AQ = 0.954 (Giné-Garriga et al., 2009). The tester needed one previous demonstration and one trial of testing before conducting the test.

2.2.2. Comparison tests

Comparison tests included: (a) fast and normal gait speed (FGS and NGS) recording the time it took each participant to walk the central 8 m of a 12-m course, and dividing the distance (8 m) by the time to derive the gait speed (Guralnik et al., 1994, 1995); (b) five chair rises (Cr) with a 42 cm height chair from the seat to the ground with the subject's arms across their chest (Guralnik et al., 1994, 1995; Curb et al., 2006); (c) single-leg balance time (SLB) adding the time from two trials lifting the same leg (Vellas et al., 1997; Curb et al., 2006); (d) POMA (Tinetti, 1986; Tinetti et al., 1988); and (e) two maximal isometric quadriceps and hamstrings contraction strength (MVC) for each leg performed during 5 s with a 45 s rest period between each, obtained at a 60° knee joint angle (0° = full knee extension) using an isokinetic dynamometer (Con-Trex. Human Kinetics 1.7.1, Hans and Rüth), and using the highest value for data analysis.

2.3. Data analysis

Descriptive statistics (mean ± SD) were used to summarize the data. Prior to all the analyses, the one-sample Kolmogorov–Smirnov test was used to analyze the normality of the modified TGUG test and comparison tests. Parametric 95% confidence intervals (95% CI) were calculated for the 10th and 90th percentiles of the modified TGUG test performance for community-dwelling low function elderly people (group 1 = recurrent fallers), and 30 active elderly population either without a previous history of falls or with only one fall reported, included in the sample of a previous study (group 2 = non- or once-fallers) (Giné-Garriga et al., 2009). Concurrent validity of data obtained with the modified TGUG test was assessed by calculating Pearson correlation coefficients between the comparison tests and components of the modified TGUG test. Because of concern for right-skewed distributions in single-leg balance test, data was log-transformed; for normal-distributed data, Pearson correlation coefficient were calculated for components of the modified TGUG and selected comparison tests as shown in Table 2. For the statistical analyses, SPSS version 14.0 was used, and an alpha level of 0.05 was selected (CI = 95%).

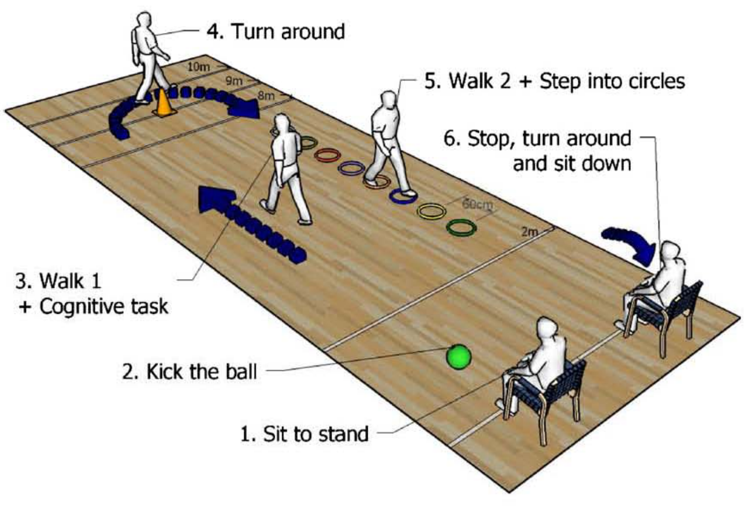


Fig. 1. Modified TGUG test achievement.

Table 2
Components of the modified TGUG compared to selected tests, and relationship between the modified TGUG test and physical performance measures.

Comparisons	Constructs tested	Correl. coeffs
TT vs. NGS	Gait with dual-task	−0.841
TT vs. FGS	Gait with dual-task	−0.748
Kick-8 m vs. NGS	Gait with dual-task cognitive	−0.776
Kick-8 m vs. FGS	Gait with dual-task cognitive	−0.686
TT-kick 8 m vs. NGS	Gait with dual-task physical	−0.736
TT-kick 8 m vs. FGS	Gait with dual-task physical	−0.660
SU vs. Cr	Lower body extremity strength	0.691
BT vs. Cr	Lower body extremity strength	0.659
AQ vs. SLB[a]	Static and dynamic balance	0.699
AQ vs. POMA[b]	Static and dynamic balance	0.795
Right knee extensor, MVC[c] vs. SU	Lower body extremity strength	−0.692
Left knee extensor MVC[c] vs. SU	Lower body extremity strength	−0.597
Right knee extensor MVC[c] vs. BT	Lower body extremity strength	−0.640
Left knee extensor MVC[c] vs. BT	Lower body extremity strength	−0.507

Notes: All Pearson correlations are statistically significant ($p < 0.05$).
[a] Data was log-transformed.
[b] Data was collected on 35 participants.
[c] Highest value of two trials used for data analysis.

3. Results

Forty-two 72.3 ± 5.5 years women volunteered to take part in the study and thirty-seven completed the testing protocol. Despite the task complexity of the test, all seniors were able to complete to modified TGUG test. Four subjects (10.8%) did not perform the step into circles task because of not feeling safe enough, scoring 0 points in the AQ; 19 subjects (51.4%) scored 1 point meaning that they were able to walk stepping one foot in each circle touching more than one, or needing more than one extra step to regain balance. For the POMA, data was collected on 35 participants because one subject felt unwell during the end of the testing and the other left before ending the testing protocol. Twenty-eight subjects (75.7%) reported 2 falls, eight subjects (21.6%) reported 3 falls, and one subject (2.7%) reported 4. Three subjects (8.1%) admitted to using a cane occasionally outdoors or for long distances. The characteristics of the subject population and the scores achieved in the comparison tests are shown in Table 1. The 10–90th percentiles for the TT of the modified TGUG performance for group 1 (recurrent fallers) were 31.95–53.57 s (95% CI = 37.96–43.67); for group 2 (non- or once-fallers) were 22.16–38.12 (95% CI = 29.10–33.31). According to the AQ, the 10–90th percentiles for group 1 were 5.5–12 points (95% CI = 7.88–9.48); and for group 2 were 11.1–16 (95% CI = 12.80–14.07). We therefore chose 34 s in the TT and 14 points in the AQ as a clinical cut-off point for normal modified TGUG test performance in community-dwelling elderly population. With 95% CI, 34 s or less as a TT were regarded as normal, as well as 14 points or more in the AQ.

Data obtained with the modified TGUG test consistently correlated with a number of performance measures at least as well as other standard measures (Table 2). TT measures were significantly associated with normal and fast gait speed tests ($p < 0.05$). The Pearson correlation coefficients were −0.841 and −0.748, respectively. Measures of kick-8 m line, were also significantly associated with normal and fast gait speed tests ($p < 0.05$). The Pearson correlation coefficients were −0.776 and −0.686, respectively. TT-kick 8 m measures were also significantly associated with normal and fast gait speed tests ($p < 0.05$). The Pearson correlation coefficients were −0.736 and −0.660, respectively. SU and BT measures were significantly associated with the five chair rises test ($p < 0.05$). The Pearson correlation coefficients were 0.691 and 0.659, respectively. SU and BT measures of the modified TGUG test also correlated significantly with right knee extensor MVC ($p < 0.05$). The Pearson correlation coefficients were −0.692 and −0.640, respectively.

With respect to the total points obtained in the AQ, these were also significantly associated with the single-leg balance test measures, after log-transforming the data ($p < 0.05$). The Pearson correlation coefficient was 0.699. Points obtained in the AQ correlated significantly to points obtained in the POMA scale ($p < 0.05$). The Pearson correlation coefficient was 0.795. Table 2 illustrates the relationship between the modified TGUG test and other measures of physical performance.

4. Discussion

The correlations between the modified TGUG test and comparison tests, including dynamometry testing, were moderately strong and statistically significant. The data from the present study provided information to support concurrent criterion validity. It has been demonstrated in the literature that construct validity can be established by correlating a new test instrument with validated, clinically accepted tests (Doménech, 2006). Specifically, the present study showed that (i) TT, kick 8 m, and TT-kick 8 m measures were significantly correlated to normal and fast gait speed, (ii) SU and BT were significantly correlated to five chair rises and right knee extensor MVC, and (iii) the total points obtained in the AQ significantly correlated to the single-leg balance measures and POMA scale.

The total time to complete the test (TT, includes both cognitive and physical dual-task), the time taken to kick the ball and walk pass the 8-m line (kick-8 m line, dual-task: cognitive task while walking), and the time taken from crossing the 8 m line and return to the chair (TT-kick 8 m, dual-task: physical task while walking) demonstrated higher inverse correlations with normal gait speed than fast speed, thus indicating the importance of assessing older people's performance at their usual pace. Montero-Odasso et al. (2005) found that the usual gait speed measurement could allow the detection of healthy elderly people at risk for adverse events. It has been previously demonstrated that walking at a fast pace might mask gait patterns and balance impairments in the elderly (Shumway-Cook et al., 2007). In the present study, subjects were asked to perform the modified TGUG test at their usual pace. Moreover, the present study demonstrated a higher inverse correlation between gait speed and the kick 8 m (cognitive task while walking) than between gait speed and TT-kick 8 m (physical task while walking). Assuming that reduced gait speed has been associated to functional decline (Guralnik et al., 1994, 1995), the implications of these findings are that counting backwards while walking is a more sensitive way to assess functional decline than a physical task such as stepping into circles while walking, included in the modified TGUG test. However, the best predictor of normal gait speed was TT, thus validating the use of both a cognitive and a physical dual-task in the modified TGUG test.

It has been previously demonstrated that dual-tasks result in diminished gait performance (Armieri et al., 2009; Beauchet et al., 2008). Dubost et al. (2006) reported increased gait variability in healthy older adults who performed simple arithmetical tasks; and Lindenberger et al. (2000) demonstrated that the dual-task demands increased with aging, especially when walking through a complex course (i.e., reduction in gait speed, increased number of

Please cite this article in press as: Giné-Garriga, M., et al., Measuring balance, lower extremity strength and gait in the elderly: Construct validation of an instrument. Arch. Gerontol. Geriatr. (2009), doi:10.1016/j.archger.2009.10.008

missteps when walking over a narrow route, as well as reduction in performance of the cognitive task). By assessing the relationship between gait speed and kick 8 m (cognitive task while walking) and TT-kick 8 m (physical task while walking), respectively, we wanted to establish criterion validity of the dual-task component with both a cognitive and physical task respectively in the modified TGUG. These type of activities mimic physical processes that are encountered in a usual day and represents the real utility of the test. On the other hand, Shumway-Cook et al. (2000) concluded that the ability to predict falls was not enhanced by adding a secondary task when performing the TGUG, although the ability to predict functional decline as predictor of future falls in some populations of elderly individuals was not reported.

Inverse correlation between SU of the modified TGUG test, and right knee extensor MVC were moderately strong, at least as strong as other standard measures (Daubney and Culham, 1999; Medell and Alexander, 2000). A sit-to-stand movement requires muscle strength greater than other daily activities, such as walking or stair climbing (Ploutz-Snyder et al., 2002). Similarly, Lord et al. (2002) demonstrated that in community-dwelling older people during a sit-to-stand performance, quadriceps strength was the most important variable in explaining the variance in sit-to-stand times (Lord et al., 2002). As shown in the present study, sufficient leg extension strength is required for being able to stand up from a chair (Aagaard et al., 2007) and for adequate balance recovery after a gait perturbation (Pavol et al., 2002; Shumway-Cook et al., 2007). Correlation between BT and knee extensor MVC also showed an inverse relationship, but were not as high as SU, however, they were statistically significant. A previous study demonstrated that the ball velocity significantly correlated with the knee extensor muscular strength of the kicking leg at a given approach angle (Masuda et al., 2005).

The data suggest that timed performance is important and has been used to successfully evaluate functional limitation. However, when attempting to quantify how older adults perform each task, timed performance suffers at the expense of how the task is performed. Total timed performance and the items assessed in the assessment questionnaire were significantly correlated ($r = -0.564$), but the explained variance was low. Therefore, data obtained with the present study showed that timed performance is a more valid measure than AQ to document physical function.

Even though AQ measures showed a positive relationship and correlated significantly to SLB and POMA measures, SLB showed weak correlation with TT, SU, BT and kick-8 m. This could have been because SLB measures were mainly related to balance, and the other measures included in the modified TGUG test, despite involving the need for postural balance, do not specifically assess it. The data from the present study is contradictory with Cho et al. (2004) who found higher significant correlation of SLB measures to the TGUG test, probably due to lower functional impairment in their sample population.

5. Conclusion

Based on the strength of the correlations obtained between components of the modified TGUG and the comparison tests, concurrent, criterion validity of the modified TGUG has been indicated. The test is simple to administer, needs a short administration time, and is feasible for older people to undertake in community settings and rehabilitation assessment in primary care.

Conflict of interest statement

None.

Acknowledgements

The authors gratefully acknowledge the support of the Barcelona primary care management (Institut Català de la Salut) for their recruitment permission. Special thanks to the staff of the Department of Physical Medicine and Rehabilitation (Vall d'Hebrón Hospital, Barcelona, Spain) for the use of the isokinetic dynamometer. We would like to thank the Facultat de Psicologia, Ciències de l'Educació i l'Esport Blanquerna for its collaboration.

References

Aagaard, P., Magnusson, P.S., Larsson, B., Kjaer, M., Krustrup, P., 2007. Mechanical muscle function, morphology, and fiber type in lifelong trained elderly. Med. Sci. Sports Exerc. 39, 1989–1996.

American Geriatrics Society, 2001. British Geriatrics Society American Academy of orthopaedic surgeons panel on falls prevention, guidelines for the prevention of falls in older persons. J. Am. Geriatr. Soc. 49, 664–672.

Armieri, A., Holmes, J.D., Spaulding, S.J., Jenkins, M.E., Johnson, A.M., 2009. Dual task performance in a healthy young adult population: results from a symmetric manipulation of task complexity and articulation. Gait Posture 29, 346–348.

Beauchet, O., Annweiler, C., Allali, G., Berrut, G., Herrmann, F.R., Dubost, V., 2008. Recurrent falls and dual task-related decrease in walking speed: is there a relationship? J. Am. Geriatr. Soc. 56, 1265–1269.

Berg, K., Wood-Dauphinee, S., Williams, J.I., Maki, B., 1992. Measuring balance in the elderly: validation of an instrument. Can. J. Public Health 83 (Suppl. 2), S7–S11.

Bischoff, H.A., Stähelin, H.B., Monsch, A.U., Iversen, M.D., Weyh, A., von Dechend, M., Akos, R., Conzelmann, M., Dick, W., Theiler, R., 2003. Identifying a cut-off point for normal mobility: a comparison of the timed 'up and go' test in community-dwelling and institutionalised elderly women. Age Ageing 32, 315–320.

Charlton, R.A., Barrick, T.R., McIntyre, D.J., Shen, Y., O'Sullivan, M., Howe, F.A., Clark, C.A., Morris, R.G., Markus, H.S., 2006. White matter damage on diffusion tensor imaging correlates with age-related cognitive decline. Neurology 66, 217–222.

Chiu, A.Y., Au-Yeung, S.S., Lo, S.K., 2003. A comparison of four functional tests in discriminating fallers from non-fallers in older people. Disabil. Rehabil. 25, 45–50.

Cho, B., Scarpace, D., Alexander, N.B., 2004. Tests of stepping as indicators of mobility, balance, and fall risk in balance-impaired older adults. J. Am. Geriatr. Soc. 52, 1168–1173.

Craig, C.L., Marshall, A.L., Sjöström, M., Bauman, A.E., Booth, M.L., Ainsworth, B.E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J.F., Oja, P., 2003. International Physical Activity Questionnaire: 12-country reliability and validity. Med. Sci. Sports Exerc. 35, 1381–1395.

Curb, J.D., Ceria-Ulep, C.D., Rodriguez, B.L., Grove, J., Guralnik, J., Willcox, B.J., Donlon, T.A., Masaki, K.H., Chen, R., 2006. Performance-based measures of physical function for high-function populations. J. Am. Geriatr. Soc. 54, 737–742.

Daubney, M.E., Culham, E.G., 1999. Lower-extremity muscle force and balance performance in adults aged 65 years and older. Phys. Ther. 79, 1177–1185.

Doménech, J.M., 2006.In: Fundamentos de Diseño y Estadística. Correlación y Regresión Lineal, first ed. Signo, Barcelona, (in Spanish), pp. 71–76.

Dubost, V., Kressig, R.W., Gonthier, R., Herrmann, F.R., Aminian, K., Najafi, B., Beauchet, O., 2006. Relationships between dual-task related changes in stride velocity and stride time variability in healthy older adults. Hum. Mov. Sci. 25, 372–382.

Fried, L.P., Bandeen-Roche, K., Chaves, P.H., Johnson, B.A., 2000. Preclinical mobility disability predicts incident mobility disability in older women. J. Gerontol. A: Biol. Sci. Med. Sci. 55, M43–M52.

Giné-Garriga, M., Guerra, M., Marí-Dell'Olmo, M., Martin, C., Unnithan, V.B., 2009. Sensitivity of a modified version of the 'Timed Get Up and Go' Test to predict fall risk in the elderly: a pilot study. Arch. Gerontol. Geriatr. 49, e60–e66.

Guralnik, J.M., Simonsick, E.M., Ferrucci, L., Glynn, R.J., Berkman, L.F., Blazer, D.G., Scherr, P.A., Wallace, R.B., 1994. A Short Physical Performance Battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J. Gerontol. 49, M85–M94.

Guralnik, J.M., Ferrucci, L., Simonsick, E.M., Salive, M.E., Wallace, R.B., 1995. Lower-extremity function in persons over the age of 70 years as predictor of subsequent disability. N. Engl. J. Med. 332, 556–561.

Katsiaras, A., Newman, A.B., Kriska, A., Brach, J., Krishnaswami, S., Feingold, E., Kritchevsky, S.B., Li, R., Harris, T.B., Schwartz, A., Goodpaster, B.H., 2005. Skeletal muscle fatigue, strength, and quality in the elderly: the Health ABC Study. J. Appl. Physiol. 99, 210–216.

Lindenberger, U., Marsiske, M., Baltes, P.B., 2000. Memorizing while walking: increase in dual-task costs from young adulthood to old age. Psychol. Aging 15, 417–436.

Lord, S.R., Rogers, M.W., Howland, A., Fitzpatrick, R., 1999. Lateral stability, sensorimotor function and falls in older people. J. Am. Geriatr. Soc. 47, 1077–1081.

Lord, S.R., Murray, S.M., Chapman, K., Munro, B., Tiedemann, A., 2002. Sit-to-stand depends on sensation, speed, balance, and psychological status in addition to strength in older people. J. Gerontol. A: Biol. Sci. Med. Sci. 57, M539–M543.

Masuda, K., Kikuhara, N., Demura, S., Katsuta, S., Yamanaka, K., 2005. Relationship between muscle strength in various isokinetic movements and kick performance among soccer players. J. Sports Med. Phys. Fitness 45, 44–52.

Medell, J.L., Alexander, N.B., 2000. A clinical measure of maximal and rapid stepping in older women. J. Gerontol. A: Biol. Sci. Med. Sci. 55, M429–M433.

Montero-Odasso, M., Schapira, M., Soriano, E.R., Varela, M., Kaplan, R., Camera, L.A., Mayorga, L.M., 2005. Gait velocity as a single predictor of adverse events in healthy seniors aged 75 years and older. J. Gerontol. A: Biol. Sci. Med. Sci. 60, M1304–M1309.
Ortega, M.A., Roca, G., Iglesias, M., Jurado, J.M., 2004. Patients over-using a primary care centre: their social, demographic and clinical characteristics, and their use of health service facilities. Aten. Primaria 33, 78–85 (in Spanish).
Pavol, M.J., Owings, T.M., Foley, K.T., Grabiner, M.D., 2002. Influence of lower extremity strength of healthy older adults on the outcome of an induced trip. J. Am. Geriatr. Soc. 50, 256–262.
Ploutz-Snyder, L.L., Manini, T., Ploutz-Snyder, R.J., Wolf, D.A., 2002. Functionally relevant thresholds of quadriceps femoris strength. J. Gerontol. A: Biol. Sci. Med. Sci. 57, M144–M152.
Podsiadlo, D., Richardson, S., 1991. The Timed "Up and Go": a test of basic functional mobility for frail elderly persons. J. Am. Geriatr. Soc. 39, 142–148.
Reuben, D.B., Herr, K.A., Pacala, J.T., Potter, J.F., Pollock, B.G., Semla, T.P., 2002. In: Malden, M.A. (Ed.), Geriatrics at Your Fingertips. Blackwell Science, for the American Geriatrics Society, pp. 1–229.
Shumway-Cook, A., Brauer, S., Woollacott, M., 2000. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. Phys. Ther. 80, 896–903.
Shumway-Cook, A., Guralnik, J.M., Phillips, C.L., Coppin, A.K., Ciol, M.A., Bandinelli, S., Ferrucci, L., 2007. Age-associated declines in complex walking task performance: the Walking InCHIANTI Toolkit. J. Am. Geriatr. Soc. 55, 58–65.
Tinetti, M.E., 1986. Performance-oriented assessment of mobility problems in elderly patients. J. Am. Geriatr. Soc. 34, 119–126.
Tinetti, M.E., Speechley, M., Ginter, S.F., 1988. Risk factors for falls among elderly persons living in the community. N. Engl. J. Med. 319, 1701–1707.
Tinetti, M.E., Inouye, S.K., Gill, T.M., Doucette, J.T., 1995. Shared risk factors for falls, incontinence, and functional dependence. Unifying the approach to geriatric syndromes. J. Am. Med. Assoc. 273, 1348–1353.
Vellas, B.J., Wayne, S.J., Romero, L., Baumgartner, R.N., Rubenstein, L.Z., Garry, P.J., 1997. One-leg balance is an important predictor of injurious falls in older persons. J. Am. Geriatr. Soc. 45, 735–738.
Ware J.Jr., Kosinski, M., Keller, S.D., 1996. A 12-item short-form health survey: construction of scales and preliminary tests of reliability and validity. Med. Care 34, 220–233.
Woollacott, M., Shumway-Cook, A., 2002. Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture 16, 1–14.
Yesavage, J.A., Brink, T.L., Rose, T.L., Lum, O., Huang, V., Adey, M., Leirer, V.O., 1983. Development and validation of a geriatric depression screening scale: a preliminary report. J. Psychiatr. Res. 17, 37–49.

Please cite this article in press as: Giné-Garriga, M., et al., Measuring balance, lower extremity strength and gait in the elderly: Construct validation of an instrument. Arch. Gerontol. Geriatr. (2009), doi:10.1016/j.archger.2009.10.008

4.3 Publication three

Giné-Garriga M, Guerra M, Pagès E, Manini TM, Jiménez R, Unnithan VB. The effect of functional circuit training on physical frailty in frail older adults: a randomized controlled trial. *Journal of Aging and Physical Activity* [In press].

THE UNIVERSITY of NORTH CAROLINA
GREENSBORO
School of Health and Human Performance

Department of Kinesiology
Jennifer L. Etnier, Ph.D. Associate Professor, FACSM
336.334.3037/JLEtnier@uncg.edu

May 4, 2010

Dear Ms. Maria Giné-Garriga,

Upon the recommendation of the Associate Editor, it is a pleasure to accept your manuscript entitled "The Effect of Functional Circuit Training on Physical Frailty in Frail Older Adults: A Randomized Controlled Trial" in its current form for publication in the Journal of Aging and Physical Activity.

Thank you for submitting your manuscript to the Journal of Aging and Physical Activity.

Sincerely,

Dr. Jennifer Etnier
Editor in Chief, Journal of Aging and Physical Activity
jletnier@uncg.edu

THE EFFECT OF FUNCTIONAL CIRCUIT TRAINING ON PHYSICAL FRAILTY IN FRAIL OLDER ADULTS: A RANDOMIZED CONTROLLED TRIAL

Maria Giné-Garriga[1,2], MS; Míriam Guerra[1], PhD, MD; Esther Pagès[3], PhD, MD; Todd M. Manini[4], PhD; Rosario Jiménez[5], MD; Viswanath B. Unnithan[6], PhD.

[1]FPCEE Blanquerna. Universitat Ramon Llull, Barcelona, Spain. Department of Physical Activity and Sport Sciences.

[2]Primary Health Care of Barcelona. Department of Physical Activity and Health. Institut Català de la Salut.

[3]Vall d'Hebron Hospital, Barcelona, Spain. Department of Physical Medicine and Rehabilitation.

[4]Institute on Aging, Department of Aging and Geriatric Research, University of Florida, Gainesville FL.

[5]Primary Health Care Vallcarca - Sant Gervasi, Barcelona, Spain.

[6]Sport Department, Deanery of Sciences and Social Sciences, Liverpool Hope University, Liverpool, United Kingdom.

CORRESPONDENCE

Address correspondence to Maria Giné-Garriga. Department of Physical Activity and Sport Sciences. FPCEE Blanquerna, Universitat Ramon Llull. C/ Císter 34, 08022 Barcelona, Spain. E-mail: mariagg@blanquerna.url.edu. Telephone: +34 675785983. Fax: +34 93 2533031.

ABSTRACT

The purpose of this study was to evaluate whether a 12-week functional circuit training program (FCT) could alter markers of physical frailty in a group of frail community-dwelling adults. Fifty-one individuals (31 F, 20 M), mean age (SD) 84 (2.9) years old, met frailty criteria and were randomly assigned into two groups (FCT=26, control group, CG=25). FCT underwent a 12-week exercise program. CG met once a week for health education meetings. Measures of physical frailty, function, strength, balance and gait speed, were assessed at week 0, 12 and 36. Physical frailty measures in FCT showed significant ($p<.05$) improvements relative to those in the CG (Barthel index at week 0 and 36: 73.41 (2.35) and 77.0 (2.38) for the FCT and 70.79 (2.53) and 66.73 (2.73) for the CG). These data indicate that a FCT program is effective in improving measures of function and reducing physical frailty among frail older adults.

INTRODUCTION

The concept of frailty has long been associated with advancing age but only recently has it been specifically defined as a medical syndrome (Bergman et al., 2007; Ferrucci et al., 2004; Fried, Ferrucci, Darer, Williamson, & Anderson, 2004; Fried et al., 2001). Buchner and Wagner (1992) regarded physical frailty as a precursor state to disability and dependence on others for daily activities. It has also been defined according to the results of two tests of physical abilities that are strongly associated with the development and progression of disability: the rapid-gait test and the stand-up test (Gill et al., 2002).

Physical performance is considered fundamental to the identification of frail individuals and most definitions of frailty in older people also include objective or self-report measures of functional status (Bergman et al., 2007). Medically, frailty has been defined as a clinical syndrome in which three or more of the following criteria were present: unintentional weight loss (10 lbs in past year), self-reported exhaustion, weakness, slow walking speed, and low levels of physical activity (PA) (Fried et al., 2001). Furthermore, Rockwood et al. (2005) added in their criteria for clinical measures of frailty, having difficulties in activities of daily living (ADL's).

Frailty health outcomes contribute to an increased demand for medical and social care, and are associated with increased economic costs (Ortega, Roca, Iglesias, & Jurado, 2004), and frail individuals are considered to be the group of patients that presents the most complex and challenging problems to health care professionals (Gill et al., 2002). As demographic trends indicate a rise in the older population, this healthcare burden will increase (Bergman et al., 2007; Gill, Gahbauer, Allore, & Han, 2006). Therefore, interventions designed to prevent the functional decline in frail population have the potential not only to generate health care savings (Guralnik, Alecxih, Branch, & Wiener, 2002), but also to minimize the severity of multiple chronic diseases, promote the maintenance of function, and prevent further frailty and loss of independence (Fried et al., 2004, Gill et al., 2002).

The efficacy of exercise training to improve physical function in the frail elderly has been supported by randomized controlled trials presented in a number of reviews in recent years (Beswick et al., 2008; Chin A Paw, van Uffelen, Riphagen, & van Mechelen, 2008). However, the enhanced internal validity achieved in these studies is often gained at the expense of external validity, as the study conditions tend to be far removed from routine practice in primary care settings. Interventions in many health fields (Binder et al., 2002; Eakin, Brown, Marshall, Mummery, & Larsen, 2004) that have been found to be successful in research centers might be impractical to implement in applied settings that have limited time, few resources, and many competing demands.

Moreover, studies of the effects of exercise training on frailty have been limited mainly to patients in residential care facilities (Fiatarone et al., 1994; Faber, Bosscher, Chin A Paw, & van Wieringen, 2006; Littbrand, Lundin-Olsson, Gustafson, & Rosendahl, 2009; Rydwik, Frandin, & Akner, 2004), and younger individuals (Nelson et al., 2004), or have assessed intermediate outcome measures such as strength, balance, and gait (Beswick et al., 2008; Faber et al., 2006; Landi et al., 2007; Skelton, Young, Greig, & Malbut, 1995). There was limited success from these training studies and very few focused on the reduction in physical frailty components as the main outcome measure.

Previous studies have indicated the importance of the exercise being task specific if functional ability is to be improved (Bean et al., 2004; Manini et al., 2007; Skelton & McLaughlin, 1996; de Vreede, Samson, van Meeteren, Duursma, & Verhaar, 2005).

Older people with severe physical impairment generally have a great need for assistance in ADL’s (Rosendahl et al., 2006), thus, the need to focus on ADL’s as a fundamental outcome measure is also important as an index of independent living. As a result, knowledge of how functional exercise conducted in primary care facilities affects markers of frailty and ADL’s in frail community-dwelling elderly population is limited.

In addition to the outcome measures, and the exercise type, intervention sustainability in terms of follow-up data, offers crucial information about long-term benefits. However, most intervention studies that have been conducted in frail community-dwelling elderly individuals, have shown a lack of post-training follow-up data (Binder et al., 2002, Chin A Paw et al., 2008; Hruda, Hicks, & McCartney, 2003; Shimada, Obuchi, Furuna, & Suzuki, 2004). Hence, there is a lack of evidence to support the view that functional-based exercise programs are an effective and sustainable method for altering markers of frailty, improving ADL's, and preventing or postponing functional decline in community-dwelling frail elderly individuals.

Consequently, we conducted a randomized, clinical trial that consisted of a 12-week functional circuit training program based on a combination of functional balance and strength-based exercises in a high-risk group of physically frail, elderly persons who lived at home. Six months after the end of the training program, follow-up testing was conducted to assess the sustainability of any training-induced changes. Consequently, the primary aim of the study was to determine the effect of a 12-week structured, intervention program on reducing physical frailty measures in a group of community-dwelling physically frail elderly individuals. The secondary aim of the study was to evaluate whether these improvements were sustained 6 months after the end of the training program.

METHODS

Subjects

Participants were recruited from one randomly selected primary health care center in the Barcelona area. Individuals who were eighty to ninety years of age were eligible to participate in the study. The total number of eighty to ninety year-old individuals registered in the primary health care center were n ~ 3547, and during January to March 2009 (recruitment period), ~ 2029 eighty to ninety year-old individuals attended the primary health care center.

Individuals were ineligible for the study if they were unable to walk, were undergoing an exercise program, had a diagnosis of severe dementia (not able to understand and/or follow verbal commands), or had had a stroke, hip fracture, myocardial infarction or had undergone hip- or knee- replacement surgery within the previous 6 months (n = 586).

During usual visits to their healthcare center, the ~ 2029 individuals who visited, self-reported their ability to rise from a chair or climb a flight of stairs (Manini et al., 2007). Those reporting "some" or "a lot" of difficulty in either task were invited to participate (n = 1177). Those individuals who were willing to participate and presented no exclusion criteria, were invited for physical frailty screening testing (n = 84). A total of 1093 individuals were excluded due to: declining participation in the study (n = 217), presented at least one exclusion criteria (n = 586), or reported not being able to complete the study period due to lack of time and/or travel plans (n = 290).

Physical frailty was defined according to the results of two tests of physical abilities (Gill et al., 2002; Tinetti & Speechley, 1988), and according to two questions of the center for epidemiological studies depression scale (CES-D) (Fried et al., 2001). Individuals were considered physically frail, thus invited to participate in the study, if they either required more than 10 seconds to perform a rapid-gait test (i.e., to walk along a 3 meter course and back at a quick comfortable pace), if they could not stand up five times from a seated position in a hardback chair with their arms folded (Gill et al., 2002), or if they were categorized as frail by the exhaustion criterion (Fried et al., 2001). Subjects were asked to self-report exhaustion using the following two statements of the CES-D depression scale: (a) 'I felt that everything I did was an effort'; (b) 'I could not get going'. The question was asked as 'how often in the last week did you feel this way?' and their answers graded as 0 = rarely or none of time (<1 day), 1 = some or a little of the time (1-2 days), 2 = a moderate amount of time (3-4 days), or 3 = most of the time. Subjects answering 2 or 3 were categorized as frail by the exhaustion criterion (Fried et al., 2001).

Of those individuals invited for screening testing (n = 84), based on the definition of physical frailty, 51 individuals (31 women, 20 men) were considered frail and tested at baseline (week 0) and afterwards randomly assigned into two groups (an intervention group, FCT = 26 and a control group, CG = 25) with the use of a computer-generated algorithm. According to the physical frailty criteria, 33 individuals did not meet the selection criteria and, therefore, did not participate in the study (see figure 1 for more detail).

The study personnel who maintained the randomization log were not involved in screening, testing, or training procedures. Following 12 weeks of training, participants of both the FCT and the CG reported for the end of the intervention testing session (week 12). Six months following the end of the program (week 36), participants were invited to a follow-up testing session. Written informed consent was obtained from all subjects, and a local university ethics committee gave approval for the study. Figure 1 shows the flow of participants through the study following the Consolidated Standard of Reporting Trials (CONSORT) flow diagram (Moher, Schulz, & Altman, 2001).

Measurements

Week 0 (baseline), week 12 (end of the training program) and week 36 (follow-up) assessments were completed by the same three investigators, two of whom were blinded and not involved in training the participants. For safety reasons, an assistant who had no role in the intervention and who was unaware of the study hypothesis and of the participants' group assignments was always present during testing, and during both interventions. In addition to data on physical frailty, activities of daily living measures, and measures of balance, gait, physical function, and strength were assessed. Timed performance was assessed using a 10-lap memory stopwatch (1/100s accuracy) for the field testing mentioned below.

Body composition. Body mass was measured while the individual was wearing sport clothes (no shoes) with a calibrated balance beam scale (Health-O-Meter Model 402EXP). Height was measured with a stadiometer (Seca 202). Each subject's BMI was calculated, as body weight (0.1 kilogram accuracy) divided by height (0.01 meters accuracy) squared.

Activities of Daily Living. The 10-item version of the Barthel Index (BI) using a 5-level scoring scale adapted by Shah, Vanclay, & Cooper (1989) was used to collect information about the need of assistance for basic activities of daily living and to establish a degree of independence. The total BI score when summed, ranges from 0 (total dependence) to 100 (complete independence); a score of 21 to 60 is considered severe dependence, and a score of 61 to 90 moderate dependence (Shah et al., 1989). Shah et al.'s (1989) adaptation was aimed at increasing the BI's sensitivity to change in research studies.

Measures of balance: Semi-tandem and tandem stands; and single-leg balance. Two trials of each test were performed and the best trial was used for data analysis. Test of standing balance included tandem (heel of one foot directly in front of the other foot, TS), and semi-tandem (heel of one foot beside the big toe of the other foot, ST) (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995; Guralnik et al., 1994). Timing was stopped when participants moved their feet, or when 10 seconds had elapsed. Those able to maintain the semi-tandem position for 10 seconds were further evaluated with the feet in full tandem position. Test-retest reliability and validity has previously been established in a frail institutionalized population (Guralnik et al., 1995; Guralnik et al., 1994). For single-leg balance (SLB), participants were asked to place their hands across their chest, lift their preferred leg, and stand for as long as possible. Subjects stood with their lifted foot approximately 5 cm from the medial malleolus of the stance foot without the lifted foot being in contact with the malleolus. Those participants who could stand for more than 30 seconds were asked to stop the test. The best trial (lifting the same leg both trials) was used for data analysis. The test's validity and reliability were established in an elderly population in a previous study (Vellas et al., 1997).

Measure of gait: Gait Speed. Gait speed was determined by recording the time it took each participant to walk the central 8 meters of a 12-m course at their usual, self selected pace (NGS), and then as fast as comfortably possible (FGS). The initial and final 2m were to allow for acceleration and deceleration of the participant. The distance (8m) was divided by the time to derive the gait speed. The test's validity and reliability has previously been established in a frail institutionalized population (Guralnik et al., 1995; Guralnik et al., 1994).

Measure of physical function: Modified TGUG Test. The modified TGUG Test is a physical function assessment tool that measures balance and gait with a dual-task: performing a cognitive (counting backwards from 15 to 0) and a physical task (stepping into circles) while walking. Lower extremity strength is measured by standing up from a chair and kicking as hard as possible a 19cm diameter, 0.2kg, soft sponge ball as a challenging task with the individual's dominant leg. Quantitative evaluations of performance were provided by: (a) the total time needed to perform the test (TT); (b) the time needed to stand up from a chair (42cm height from the seat to the ground) without using their arms and kick the ball (SU); (c) the time elapsed between when the subject kicked the ball to when the ball passed the 8m line (BT); (d) the time elapsed between when the subject kicked the ball and walked pass the 8m line (kick-8m line); and (e) the time from when the subject crossed the 8m line and returned to the chair (TT- Kick 8m). A qualitative evaluation was performed by the completion of an assessment questionnaire (AQ); the maximum points that could be attained were 18 (could perform each task unaided). The instructions given to perform the test and the items assessed in the AQ have been presented elsewhere (Giné-Garriga, Guerra, Marí-Dell'Olmo, Martin, & Unnithan, 2009). Moreover, the validity and reliability has been established in individuals older than 70 years of age in a previous research study (Giné-Garriga et al., in press; Giné-Garriga et al., 2009).

Lower body strength. Maximal isometric quadriceps and hamstrings contraction strength (MVC) were obtained at a 60º knee joint angle (0º = full knee extension) using an isokinetic dynamometer (Con-Trex MJ, Human Kinetics 1.7.1, Hans E. Rüth SA). Subjects were reclined 10º in a rigid chair and firmly strapped at the hip and distal thigh. The rotational axis of the dynamometer was visually aligned to the lateral femoral condyle of the subject, and the lower leg was attached to the dynamometer lever arm, 2cm above the lateral malleolus. Two quadriceps and hamstrings MVC for each leg were performed with a 45s rest period between each. Verbal encouragement was provided throughout. Furthermore, visual feedback of the dynamometer force signal was provided to the subjects on a PC screen, as it has been demonstrated that visual feedback improves maximum isometric output in dynamometry testing (Kellis & Baltzopoulos, 1996). Subjects were instructed to contract "as hard and as fast as possible" and maintain maximal voluntary isometric contraction for 5 seconds. MVC was obtained as the maximal moment of force (Nm) and normalized to body mass (Nm/kg). The highest value was used for data analyses.

Intervention group (FCT)

The intervention was conducted in an indoor primary care facility, and all participants reported to the training facility twice a week for 12 weeks. Each session lasted 45 minutes, and all protocols incorporated the overload training principle (Guyton & Hall, 2007). The intervention group underwent a functional circuit training program that focused on functional balance and lower body strength-based exercises (FCT) for the duration of 12 weeks.

All training sessions began with a warm-up, walking at their usual pace for 10 minutes, and ended with cool-down, stretching for 5 minutes. These sessions were always performed under the supervision of the same investigator; an assistant certified in first aid was always present and was encouraged to report any negative sign or symptom resulting from the exercises during the classes. During the exercise period, participants were instructed to continue their routine daily activities and not perform any new exercise except for FCT.

During the FCT, participants performed one day of balance-based activities and one day of lower-body strength-based exercises, both were combined with function-focused activities. Balance activities were designed to challenge the visual (e.g. eyes open/closed), vestibular (e.g. move head), and somatosensory (e.g. stand on foam) systems. Static balance consisted of two-leg and one-leg balance with toes or heels raised, and tandem standing with eyes open/ closed using different surfaces. When training dynamic balance, activities such as walking on different surfaces, with varied elevations, and performing a dual task (cognitive and functional task such as catching, throwing, and reaching); incorporating different gait patterns (e.g. narrow walking, longer strides, zig-zag walking); and with variations in gait speed, were performed. Balance exercises included function-focused activities such as: walking with obstacles, while wearing standard sunglasses (worn over corrective lenses as needed) to mimic a semidark environment, walking while carrying a package that obstructed the view of the feet, and walking involving picking up objects from the floor. Four sets of exercises of increasing complexity were designed, when the easiest step was achieved, without needing help, the individual could perform the more complex set of exercises.

Lower body exercises included functional tasks such as rising from a chair, stair climbing, knee bends, floor transfer, lunges, leg squat, leg extension, leg flexion, calf raise, and abdominal curl using ankle weights. An 8-repetition maximum without weight was established at the first training session and repeated at the second training session. Participants were instructed to perform strength training at a perceived exertion intensity of 12-14 (somewhat hard) (Borg, 1970), without holding their breath during exercises to minimize exercise-induced blood pressure elevations.

Initially the participants performed one to two sets of six to eight repetitions of each exercise; the number of repetitions was increased when a participant was able to complete 8 repetitions at a lower perceived exertion intensity; the maximum number of repetitions were 15. The load was increased 0.5 kg when a subject could perform 15 repetitions at a lower perceived exertion intensity up to a maximum of 2kg. This protocol was developed in our laboratory based on an 8-week pilot training study.

Control group (CG)

Subjects who were randomly assigned to the control group were asked to continue their routine daily activities and received their usual care from their primary care practice whenever it was needed. In order to control for the fact that the intervention group may have improved their performance simply due to exposure to the researchers and the socialization effect of working in a group (Littbrand et al., 2009), the control subjects met once a week in the training facility (twelve times) for social meetings with the researchers. Four health educational sessions of 60 minutes were conducted, as part of the 12 visits. The classes included health topics that were relevant to older adults such as nutrition, medication use, foot care, sleep hygiene, and other health-related areas.

Outcomes

The primary outcome was the improvement in physical frailty components. This was evaluated by a change in: the BI score, the rapid-gait test, and the stand-up test measures, between week 0 to week 12 and from week 12 to week 36. Secondary outcomes were assessed by changes in: balance, gait, physical function, and strength measures, between week 0 to week 12 and from week 12 to week 36. Week 12 data were available for all the participants with the exception of 4 participants in the FCT group, who refused to complete the assessment because of a loss of interest in the study (n = 1), and health problems (n = 3). Six participants in the control group missed the week 12 assessments because of a loss of interest in the study (n = 4), health problems (n = 1), and relocation to another city (n = 1) (see figure 1 for more detailed information). Week 36 data were available for 18 individuals of the FCT and 7 individuals in the CG. Four individuals in the FCT refused to complete the assessment because of a loss of interest in the study (n = 1), health problems (n = 2), and being involved in another study (n = 1). Twelve individuals in the CG couldn't be assessed due to the fact they were engaged in other activities at the follow-up time (n = 11), and 1 individual died (see figure 1 for more detail).

Data analysis

Sample size calculations were estimated for significant changes in physical frailty components. Thirty-eight participants (19 per group) were needed to detect a 20%

improvement in the rapid-gait test, at a power of 80% and an $\alpha = .05$, a standard deviation of 30% of the mean, and a 20% dropout rate. Forty-four participants (22 per group) were needed to detect a 15% improvement in the stand-up test, analyzed with the same criteria as the rapid-gait test. Fifty-one frail older adults were recruited for the study.

Week 0 (baseline) demographic characteristics were compared between the groups by independent t-tests, except for a few cases where required conditions were not satisfied, and Mann-Whitney U test was used as a nonparametric alternative. Chi-square tests were used for between-group comparison of categorical variables at baseline. Because of missing data, all longitudinal analyses for variables that were measured at the three time points (week 0, 12 and 36) were performed using linear mixed modelling (Cnaan, Laird, & Slasor, 1997). Thus, linear mixed modelling was performed for all continuous variables (physical frailty, balance, gait, physical function, and isometric dynamometry). This mathematical approach can be applied to repeated measures data from unbalanced designs (i.e. multiple independent variables with unbalanced multiple levels on each factor). This type of analysis can also cope with the mixture of random and fixed level effects that occur with ‘real-world’ data (Cnaan et al., 1997). Furthermore, it can also cope with missing data and ‘nested’ (hierarchical models).

The primary focus of this analysis was on the significance of the interaction between group (FCT and CG) and time (week 0, 12, and 36). Within the framework of the linear mixed model analysis, when interactions were significant ($p < .05$), Bonferroni post-hoc tests were used. For all outcome measures, adjusted means and standard errors were calculated and used to compute 95% confidence intervals. These confidence intervals were adjusted for any between-group differences at baseline, in order to provide a best estimate of the true effect of the intervention.

We included gender as a factor to assess whether there was a systematic effect of gender on all the outcome measures; if there was no effect, gender was not included in the subsequent analyses. All outcome measures were normally distributed, thus satisfying the basic assumption for linear mixed modelling.

All investigators involved in the data analysis were blinded to the treatment assignment.

For the statistical analyses, SPSS version 17.0 software (SPSS, Chicago, IL) was used, and an alpha level of .05 was selected.

RESULTS

Individual characteristics and compliance with the protocol

Fifty one individuals were randomized: 26 to the FCT and 25 to the CG. Participants in the FCT were required to complete 24 sessions, and their compliance was 90%. There was a dropout rate of 15% at week 12 (4 participants did not complete the intervention, see figure 1 for more detail). Moreover, all participants in the FCT were compliant with the exercise prescription except for one woman who required rest (sitting on a chair) after each exercise during the first three weeks. Participants in the CG were required to complete 12 sessions, and their compliance was 76%. There was a dropout rate of 24% (6 participants) at week 12. There were no adverse events during the study period. Six months following the end of training (week 36 follow-up) there was a dropout rate of 18% in the FCT (of the 22 participants that completed the intervention, 4 participants did not report for the week 36 testing, see figure 1 for more detail).

The week 0 characteristics of the participants are presented in table 1. The mean age (SD) of participants in the FCT and CG groups were 83.9 (2.8) and 84.1 (3), respectively. As shown in table 1, there were no significant differences in week 0 characteristics of the two groups.

Primary outcome measures

No gender effect was evident in all the outcome variables, so that the data was pooled. FCT participants had greater improvements than those in the CG in all physical frailty measures, these improvements were maintained in the week 36 follow-up, with significant group-by-time comparisons by the end of the study (see table 2 and figure 2). The BI score, the rapid gait test, and the stand up test measures followed similar patterns and improved significantly ($p < .05$) in the FCT from baseline to week 12 measures, and from baseline to week 36 follow-up with no significant change in the CG. Physical frailty measures (BI score, the rapid gait test, and the stand up test) showed a significant decline following cessation of training, but group-by-time interactions between week 0 and week 36 measures remained significant. In contrast, individuals in the CG demonstrated no significant changes or decreased their week 12 and week 36 measures with respect to their week 0 values. The effects of the exercise program on the primary outcome measurements are shown in table 2.

Secondary outcome measures

A significant ($p < .05$) group effect was established for all week 12 and week 36 measures; for every dependent variable FCT performed better than the CG. Apart from one variable, no gender effect was identified so that the data was pooled. The left knee extension-maximal voluntary contraction variable showed a significant ($p < .05$) interaction between gender and group at week 36 measures, male subjects demonstrated a significantly ($p < .05$) higher performance compared to females. The effects of the exercise program on selected secondary outcome measurements are shown in table 3.

With respect to balance measures, FCT participants had greater improvements than those in the CG from baseline to week 12 measures (end of training), that also were sustained in the week 36 follow-up testing, with significant group-by-time interactions by the end of the study (see table 3). The semi-tandem and tandem stance improved significantly ($p < .05$) in the FCT from baseline to week 12 measures, and from baseline to week 36 follow-up. These two variables also showed a non-significant decline after cessation of training ($p = .696$, $p = .131$, respectively from week 12 to week 36). The single-leg balance measures showed a significant improvement of the FCT from baseline to week 12 ($p < .001$), but there was a reversibility of the single-leg balance gains from baseline to the week 36 follow-up ($p = .953$).

Normal and fast gait speed measures showed significantly ($p < .05$) greater improvements in the FCT participants than in the CG, and these improvements in gait speed were maintained from baseline to the week 36 follow-up. FGS showed a non-significant decline in speed following the cessation of training at week 12 ($p = .064$).

Physical function variables assessed with the modified timed get up and go test showed significant improvements from week 0 to week 12 measures in the FCT compared to the CG ($p < .05$) except for the ball time measure. The assessment questionnaire and the total time to perform the test also showed a significant improvement from week 0 to week 36 follow-up ($p = .009$, $p = .01$, respectively), although both measures showed a significant decline following cessation of training. Stand-up, ball time, kick-8m, and TT-kick 8m measures showed a reversibility of training effects from baseline to week 36 follow-up (see table 3).

With respect to the isometric dynamometry testing, maximum voluntary left knee extensor strength demonstrated significant ($p < .001$) increases in the FCT individuals from week 0 to week 12 measures compared to the CG. These gains returned to baseline by the week 36 follow-up. Maximum voluntary right knee extensor, right knee flexor, and left knee flexor torque did not show any significant improvement in isometric strength in the FCT individuals at week 12 and week 36 measures.

DISCUSSION

The two major findings of this study were that: (1) a functional circuit training program that focused on functional balance and lower body strength-based exercises (FCT) was effective in improving performance in physical measures, which led to a reduction in markers of physical frailty in community-dwelling frail older adults, and (2) these improvements were sustained in selected variables 6 months after the end of the training program.

The stimulus of the FCT induced improvements in all physical frailty measurements at week 12. The Barthel index score, the rapid-gait test and the stand-up test focused on functional tasks used in everyday activities. The importance of incorporating functional exercises when designing an intervention aiming to improve physical function in frail older adults had been documented in previous studies (Ferrucci et al., 2004; Manini et al., 2007; Skelton & McLaughlin 1996). The functional exercises included in our program were specifically designed to mimic everyday tasks; even though some exercises were slightly similar, they were not identical to the outcome measures. Given the principle of specificity of training (Brooks, Fahey, White, & Baldwin, 2000), improvements in function could be explained by neuromuscular adaptations in neural control of movement, which are likely contributors to functional adaptations. These adaptations could potentially comprise of changes in the neural activation of muscles, with modifications occurring in both intramuscular and intermuscular coordination (Grabiner & Enoka, 1995). Such adaptations may include decreased antagonist coactivation (Carolan & Cafarelli, 1992), improved coordination of synergist muscles (Carolan & Cafarelli, 1992), increased neural drive to agonist muscles resulting in the recruitment of additional motor units (Akima et al., 1999), and increased motor unit firing rates (Patten, Kamen, & Rowland, 2001).

The improvements in physical frailty measurements were sustained 6 months after the training ended. A possible mechanism for this sustainability is that neural adaptations caused by training seem to be maintained for longer periods of time than strength related gains (de Vreede et al., 2005). The motor learning that occurs during training results in a consolidation of the patterns of intermuscular and intramuscular coordination that are specific to the particular movements performed repetitively throughout training (de Vreede et al., 2005). The effectiveness with which these adaptations transfer to related movements depends on the similarity between those muscle activation patterns consolidated through the regular performance of the training exercise and those required during different movement tasks. Skelton et al. (1995) aimed to assess the effects of a 12-week intervention designed to specifically strengthen the muscles considered relevant for the functional tasks but without mimicking functional measurements. These authors showed greater improvements in muscle strength than in functional abilities. Our week 36 follow-up measures of physical frailty extend the evidence about the importance of the exercise being task specific if functional ability is to be improved.

The current training program demonstrated significant improvements in balance and gait measures in the FCT compared to the CG at week 12. Nelson et al. (2004) suggested that improvements in physical performance tend to occur along with those occurring in balance. Data from the present study are in agreement with previous training programs that have shown improvements in gait speed and balance performance in an elderly population (Fiatarone et al., 1994; Islam et al., 2004). Semi-tandem and tandem stance values were still above baseline 6 months after the cessation of the training program. The single-leg stance measure, however, showed a reversibility of single-leg balance gains by week 36. The main difference between single-leg stance and the other balance measures assessed in the present study is that the single-leg stance places a greater demand on the quadriceps and hip flexor and extensor muscles (Daubney & Culham, 1999). Consequently, the reversibility in the gains made in the single-leg stance could be linked to the inability to maintain selected strength measurements 6 months after the end of training. Evidence exists in the literature to suggest that strength gains may be maintained between 5 to 27 weeks after cessation of training in older adults (Fatouros et al., 2005; Lemmer et al., 2000). As shown by Fatouros et al. (2005), all training induced gains in strength were abolished after 4 to 8 months after training ceased. Furthermore, normal and fast gait speed also showed significant improvements from baseline to the week 36 follow-up. This finding is in disagreement with Lopopolo, Greco, Sullivan, Craik, & Mangione's review (2006), which concluded that exercise influences only slow walking speed in elderly people. Perhaps, due to the specificity of training principle, FGS would be expected to improve when step cadence and frequency of stepping was specifically trained, as occurred in the present study.

Physical function assessed with the MTGUG test improved in all variables except for the ball time measure in the week 12 assessment. The MTGUG test measures balance and gait with a dual-task. With normal aging, structural changes of the brain occur, especially in the prefrontal areas, regions that have been associated with the executive function and attentional systems (Charlton et al., 2006). The improvement in the performance of two attention-demanding tasks could be also explained by neuromuscular adaptations in neural control of movement given the principle of specificity of training (Brooks et al., 2000) stated earlier in the discussion. BT did not demonstrate any improvement in week 12 measures, probably because the training study did not specifically include a kicking task. The TT and the AQ measurements were sustained at the week 36 follow-up. However, the stand up, kick - 8m, and TT-Kick 8m measures in the MTGUG test showed a reversibility of training effects at week 36 follow-up back to week 0 measures. The stand up test in the physical frailty measures showed a significant improvement at week 36 follow-up. The main difference between both tests is that the stand-up test assesses muscular quadriceps endurance, and the SU of the MTGUG assesses mainly muscular quadriceps strength and reaction time. As shown in previous research, long term sustainability of strength gains is quite difficult to achieve (Fatouros et al., 2005; Lemmer et al., 2000), and the FCT didn't specifically train reaction time.

With respect to the dynamometry testing, left knee extensor isometric strength was the only measure which improved at week 12 measures. In our study population, most of the subjects were right leg dominant (73%), therefore, there was a greater capacity for improvement in the left lower extremities due to the lower starting point (Fiatarone et al., 1994, Hubbard, Fallah, Searle, Mitnitski, & Rockwood, 2009). Furthermore, the specificity of the FCT program led to a greater stimulus for increased extensor muscle strength (e.g. rising from a chair, stair climbing, leg extension). There was not a sustainability of the LKE strength gains in week 36 follow-up. As stated previously, decrements in strength occur quite rapidly following the cessation of training (Fatouros et al., 2005; Lemmer et al., 2000). Moreover, FCT aimed to improve function rather than isometric strength, thus, it is plausible that impairments limiting muscular strength did not change because the exercises were of insufficient intensity to produce gains in this domain. The non-significant improvement of strength over time may also reflect age-related changes in this population. If muscular strength was to be improved, the training program design would need to be different (Skelton et al., 1995).

There are some limitations to this efficacy trial. The FCT program aimed to offset the major physical parameters of frailty (e.g. wasting, loss of endurance, decreased balance and mobility, slowed performance, and relative inactivity). Hence, the authors didn't assess PA levels and unintentional weight loss as screening criteria, as suggested in Fried et al. (2001). Measuring PA levels accurately normally involves the overlap of three techniques. These are observational, perceptual (self-report) and some form of objective measurement such as accelerometry or doubly-labelled water (Vanhees et al., 2005). This was beyond the scope of the present study. One of the three test administrators was aware of the composition of the groups. However, standardized guidance and motivation were provided for all participants during all tests. When participating in supervised exercise programs, participants often do not continue the activity after the formal program ends. Despite these limitations, the post-intervention data demonstrated that most improvements remained significant at the 6-month follow-up. These findings are encouraging with regard to the sustainability of a short-duration FCT program.

FCT was tolerated well by participants, is a short, low-tech and low-cost form of exercise and therefore potentially suitable for clinical settings and primary care centers. In summary, our findings indicate that a 12-week FCT program which focused on functional balance and lower body strength-based exercises conducted in a primary care setting is a safe, effective and sustainable intervention in older physically frail community-dwelling adults. The program led to fewer functional limitations and reduced physical impairments, leading to a reduction in physical frailty parameters, which were maintained 6 months after the cessation of training. This type of intervention may help in the prevention or postponement of frailty that is severe enough to cause loss of independence.

ACKNOWLEDGEMENTS

This work was supported by a research award from the IDIAP Jordi Gol, Primary Healthcare Research Institution, Barcelona, Spain.

Work was performed at the Vallcarca – Sant Gervasi Primary Care Center, located in Barcelona. Special thanks to: Mrs. Esperanza Palacios, Mrs. Palmira Villafuerte, and Mrs. Isabel Martínez.

The authors wish to acknowledge Marc Marí-Dell'Olmo of the CIBER of Epidemiology and Public Health (Agència de Salut Pública de Barcelona), and Dr. Greg Atkinson of the Research Institute for Sport and Exercise Science (Liverpool John Moores University, Liverpool, UK) for the statistics assistance.

We thank the FPCEE Blanquerna (Ramon Llull University) and Primary Care of Barcelona management of the Institut Català de la Salut for its collaboration.

REFERENCES

Akima, H., Takahashi, H., Kuno, S.Y., Masuda, K., Masuda, T., Shimojo, H., et al. (1999). Early phase adaptations of muscle use and strength to isokinetic training. *Medicine and Science in Sports and Exercise*, 31, 588-594.

Bean, J.F., Herman, S., Kiely, D.K., Frey, I.C., Leveille, S.G., Fielding, R.A., et al. (2004). Increased Velocity Exercise Specific to Task (InVEST) training: a pilot study exploring effects on leg power, balance, and mobility in community-dwelling older women. *Journal of the American Geriatrics Society*, 52, 799-804.

Bergman, H., Ferrucci, L., Guralnik, J., Hogan, D.B., Hummel, S., Karunananthan, S., et al. (2007). Frailty: An Emerging Research and Clinical Paradigm-Issues and Controversies. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 62, M731-M737.

Beswick, A.D., Rees, K., Dieppe, P., Ayis, S., Gooberman-Hill, R., Horwood, J., et al. (2008). Complex interventions to improve physical function and maintain independent living in elderly people: a systematic review and meta-analysis. *Lancet*, 371, 725-735.

Binder, E.F., Schechtman, K.B., Ehsani, A.A., Steger-May, K., Brown, M., Sinacore, D.R., et al. (2002). Effects of exercise training on frailty in community-dwelling older adults: results of a randomized, controlled trial. *Journal of the American Geriatrics Society*, 50, 1921-1928.

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine*, 2, 92-98.

Brooks, G.A., Fahey, T.D., White, T.P., & Baldwin, K.W. (2000). *Exercise physiology: Human bioenergetics and its applications*. New York: McGraw-Hill.

Buchner, D.M., & Wagner, E.H. (1992). Preventing frail health. *Clinics in Geriatric Medicine*, 8, 1-17.

Carolan, B., & Cafarelli, E. (1992). Adaptations in coactivation after isometric resistance training. *Journal of Applied Physiology*, 73, 911-917.

Charlton, R.A., Barrick, T.R., McIntyre, D.J., Shen, Y., O'Sullivan, M., Howe, F.A., et al. (2006). White matter damage on diffusion tensor imaging correlates with age-related cognitive decline. *Neurology*, 66, 217–222.

Chin A Paw, M.J.M., van Uffelen, J.G., Riphagen, I., & van Mechelen, W. (2008). The functional effects of physical exercise training in frail older people: a systematic review. *Sports Medicine*, 38, 781-793.

Cnaan, A., Laird, N.M., & Slasor, P. (1997). Using the general linear mixed model to analyse unbalanced repeated measures and longitudinal data. *Statistics in Medicine*, 16, 2349-2380.

Daubney, M.E., & Culham, E.G. (1999). Lower-extremity muscle force and balance performance in adults aged 65 years and older. *Physical Therapy*, 79, 1177-1185.

Eakin, E.G., Brown, W.J., Marshall, A.L., Mummery, K., & Larsen, E. (2004). Physical activity promotion in primary care: bridging the gap between research and practice. *American Journal of Preventive Medicine*, 27, 297-303.

Faber, M.J., Bosscher, R.J., Chin A Paw, M.J., & van Wieringen, P.C. (2006). Effects of exercise programs on falls and mobility in frail and pre-frail older adults: A multicenter randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, 87, 885-896.

Fatouros, I.G., Kambas, A., Katrabasas, I., Nikolaidis, K., Chatzinikolaou, A., Leontsini, D., et al. (2005). Strength training and detraining effects on muscular strength, anaerobic power, and mobility of inactive older men are intensity dependent. *British Journal of Sports Medicine*, 39, 776-780.

Ferrucci, L., Guralnik, J.M., Studenski, S., Fried, L.P., Cutler, G.B. Jr., & Walston, J.D. (2004). Interventions on Frailty Working Group. Designing randomized, controlled trials aimed at preventing or delaying functional decline and disability in frail, older persons: a consensus report. *Journal of the American Geriatrics Society*, 52, 625-634.

Fiatarone, M.A., O'Neill, E.F., Ryan, N.D., Clements, K.M., Solares, G.R., Nelson, M.E., et al. (1994). Exercise training and nutritional supplementation for physical frailty in very elderly people. *The New England Journal of Medicine*, 330, 1769-1775.

Fried, L.P., Ferrucci, L., Darer, J., Williamson, J.D., & Anderson, G. (2004). Untangling the concepts of disability, frailty, and comorbidity: implications for improved targeting and care. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 59, M255-M263.

Fried, L.P., Tangen, C.M., Walston, J., Newman, A.B., Hirsch, C., Gottdiener, J., et al. (2001). Frailty in older adults: evidence for a phenotype. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 56, M146-M156.

Gill, T.M., Baker, D.I., Gottschalk, M., Peduzzi, P.N., Allore, H., & Byers, A. (2002). A program to prevent functional decline in physically frail, elderly persons who live at home. *The New England Journal of Medicine*, 347, 1068-1074.

Gill, T.M., Gahbauer, E.A., Allore, H.G., & Han, L. (2006). Transitions Between Frailty States Among Community-Living Older Persons. *Archives of Internal Medicine*, 166, 418-423.

Giné-Garriga, M., Guerra, M., Manini, T.M., Marí-Dell'Olmo, M., Pagès, E., & Unnithan, V.B. [In press]. Measuring Balance, Lower Extremity Strength and Gait in the Elderly: Construct Validation of an Instrument. *Archives of Gerontology and Geriatrics*.

Giné-Garriga, M., Guerra, M., Marí-Dell'Olmo, M., Martin, C., & Unnithan, V.B. (2009). Sensitivity of a modified version of the 'Timed Get Up and Go' Test to predict fall risk in the elderly: a pilot study. *Archives of Gerontology and Geriatrics*, 49, 60-66.

Grabiner, M.D., & Enoka, R.M. (1995). Changes in movement capabilities with aging. *Exercise and Sport Sciences Reviews*, 23, 65-104.

Guralnik, J.M., Alecxih, L., Branch, L.G., & Wiener, J.M. (2002). Medical and long-term care costs when older persons become more dependent. *American Journal of Public Health*, 92, 1244-1245.

Guralnik, J.M., Ferrucci, L., Simonsick, E.M., Salive, M.E., & Wallace, R.B. (1995). Lower-extremity function in persons over the age of 70 years as predictor of subsequent disability. *The New England Journal of Medicine*, 332, 556-561.

Guralnik, J.M., Simonsick, E.M., Ferrucci, L., Glynn, R.J., Berkman, L.F., Blazer, D.G., et al. (1994). A Short Physical Performance Battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 49, M85-M94.

Guyton, A.C., & Hall, J.E. (2007). *Tratado de Fisiología Médica*. (11th edition) Madrid: Elsevier.

Hruda, K.V., Hicks, A.L., & McCartney, N. (2003). Training for muscle power in older adults: effects on functional abilities. *Canadian Journal of Applied Physiology*, 28, 178-189.

Hubbard, R.E., Fallah, N., Searle, S.D., Mitnitski, A., & Rockwood, K. (2009). Impact of exercise in community-dwelling older adults. *PLoS One*, 4, e6174.

Islam, M.M., Nasu, E., Rogers, M.E., Koizumi, D., Rogers, N.L., & Takeshima, N. (2004). Effects of combined sensory and muscular training on balance in Japanese older adults. *Preventive Medicine*, 39, 1148-1155.

Kellis, E., & Baltzopoulos, V. (1996). Resistive eccentric exercise: effects of visual feedback on maximum moment of knee extensors and flexors. *The Journal of Orthopaedic and Sports Physical Therapy*, 23, 120-124.

Landi, F., Onder, G., Carpenter, I., Cesari, M., Soldato, M., & Bernabei, R. (2007). Physical activity prevented functional decline among frail community-living elderly subjects in an international observational study. *Journal of Clinical Epidemiology*, 60, 518-524.

Lopopolo, R.B., Greco, M., Sullivan, D., Craik, R.L., & Mangione, K.K. (2006). Effect of therapeutic exercise on gait speed in community-dwelling elderly people: a meta-analysis. *Physical Therapy*, 86, 520-540.

Lemmer, J.T., Hurlbut, D.E., Martel, G.F., Tracy, B.L., Ivey, F.M., Metter, E.J., et al. (2000). Age and gender responses to strength training and detraining. *Medicine and Science in Sports and Exercise*, 32, 1505-1512.

Littbrand, H., Lundin-Olsson, L., Gustafson, Y., & Rosendahl, E. (2009). The Effect of a High-Intensity Functional Exercise Program on Activities of Daily Living: A Randomized Controlled Trial in Residential Care Facilities. *Journal of the American Geriatrics* Society, 57, 1741-1749.

Manini, T., Marko, M., VanArnam, T., Cook, S., Fernhall, B., Burke, J., et al. (2007). Efficacy of resistance and task-specific exercise in older adults who modify tasks of everyday life. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 62, M616-M623.

Moher, D., Schulz, K.F., & Altman, D.G. (2001). The CONSORT statement. Revised recommendations for improving the quality of reports of parallel-group randomised trials. *Lancet*, 357, 1191–1194.

Nelson, M.E., Layne, J.E., Bernstein, M.J., Nuernberger, A., Castaneda, C., Kaliton, D., et al. (2004). The effects of multidimensional home-based exercise on functional performance in elderly people. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 59, M154-M160.

Ortega, M.A., Roca, G., Iglesias, M., & Jurado, J.M. (2004). Patients over-using a primary care centre: their social, demographic and clinical characteristics, and their use of health service facilities. *Atención Primaria*, 33, 78-85 (in Spanish).

Patten, C.T., Kamen, G., & Rowland, D.M. (2001). Adaptations in maximal motor unit discharge rate to strength training in young and older adults. *Muscle and Nerve*, 24, 542-550.

Rockwood, K., Song, X., MacKnight, C., Bergman, H., Hogan, D.B., McDowell, I., et al. (2005). A global clinical measure of fitness and frailty in elderly people. *Canadian Medical Association Journal*, 173, 489-495.

Rosendahl, E., Lindelöf, N., Littbrand, H., Yifter-Lindgren, E., Lundin-Olsson, L., Håglin, L., et al. (2006). High-intensity functional exercise program and protein-enriched energy supplement for older persons dependent in activities of daily living: a randomised controlled trial. *Australian Journal of Physiotherapy*, 52, 105-113.

Rydwik, E., Frandin, K., & Akner, G. (2004). Effects of physical training on physical performance in institutionalised elderly patients (70+) with multiple diagnoses. *Age Ageing*, 33, 13-23.

Shah, S., Vanclay, F., & Cooper, B. (1989). Improving the sensitivity of the Barthel Index for stroke rehabilitation. *Journal of Clinical Epidemiology*, 42, 703-709.

Shimada, H., Obuchi, S., Furuna, T., & Suzuki, T. (2004). New intervention program for preventing falls among frail elderly people: the effects of perturbed walking exercise using a bilateral separated treadmill. *American Journal of Physical Medicine & Rehabilitation*, 83, 493-499.

Skelton, D.A., & McLaughlin, A.W. (1996). Training Functional Ability in Old Age. *Physiotherapy*, 82, 159-167.

Skelton, D.A., Young, A., Greig, C.A., & Malbut, K.E. (1995). Effects of resistance training on strength, power, and selected functional abilities of women aged 75 and older. *Journal of the American Geriatrics Society*, 43, 1081-1087.

Tinetti, M.E., Speechley, M., & Ginter, S.F. (1988). Risk factors for falls among elderly persons living in the community. *The New England Journal of Medicine*, 319, 1701-1707.

Vanhees, L., Lefevre, J., Philippaerts, R., Martens, M., Huygens, W., Troosters, T., et al. (2005). How to assess physical activity? How to assess physical fitness? *European Journal of Cardiovascular Prevention and Rehabilitation*, 12, 102-114.

Vellas, B.J., Wayne, S.J., Romero, L., Baumgartner, R.N., Rubenstein, L.Z., & Garry, P.J. (1997). One-leg balance is an important predictor of injurious falls in older persons. *Journal of the American Geriatrics Society*, 45, 735-738.

de Vreede, P.L., Samson, M.M., van Meeteren, N.L., Duursma, S.A., & Verhaar, H.J. (2005). Functional-task exercise versus resistance strength exercise to improve daily function in older women: a randomized, controlled trial. *Journal of the American Geriatrics Society*, 53, 2-10.

Table 1. Baseline (week 0) characteristics of FCT and control groups.

Variable	FCT (n = 22)	Control (n = 19)	P-value
Age (years), mean (SD)	83.9 (2.8)	84.1 (3)	.79
Female, number (%)	13 (59.1)	12 (63.2)	.79
Anthropometrics:			
Height (cm), mean (SD)	159.7 (10)	158.6 (9.9)	.74
Weight (kg), mean (SD)	71.5 (13.2)	72 (14)	.91
BMI (kg/m^2), mean (SD)	27.9 (3.6)	28.6 (5.3)	.61
Marital Status:			
Married, partner alive, number (%)	12 (54.5)	8 (42.1)	.66
Single, never married, number (%)	2 (9.1)	2 (10.5)	.66
Widowed, number (%)	8 (36.4)	8 (42.1)	.66
Divorced, number (%)	0 (0)	1 (5.3)	.66
Medical conditions:			
Stroke, number (%)	6 (27.3)	5 (26.3)	.95
High blood pressure, number (%)	13 (59.1)	14 (73.7)	.33
Arthritis, number (%)	4 (18.2)	5 (26.3)	.53
Diabetes mellitus, number (%)	7 (31.8)	6 (31.6)	.99
Number of falls previous 12 months, median (IR)	1 (5)	2 (4)	.37*
Falls that required medical care, median (IR)	1 (5)	1 (3)	.27*
Falls that required hospitalization, median (IR)	0 (1)	0 (2)	.85*
CES-D question 1, number (%)**	13 (59.1)	12 (63.2)	.79
CES-D question 2, number (%)**	13 (59.1)	14 (73.7)	.33
Medication use:			
Number of routine medications, median (IR)	6 (12)	6 (8)	.92*
Benzodiazepine-use, number (%)	9 (40.9)	7 (36.8)	.79

Note: P-values indicate the outcome of either student t-test, chi-square tests or, where indicated*, Mann-Whitney U test.

**The present variable indicates the number of subjects considered frail only by the exhaustion criteria at baseline.

FCT = Functional Circuit Training program; SD = standard deviation; IR = interquartile range; CES-D = center for epidemiological studies depression scale.

Table 2. Primary outcome measures (physical frailty tests).

Variable	Interval	FCT (n = 22)		Control (n = 19)				
		Mean (SD)	95% CI	Mean (SD)	95% CI	Effect tested	p-value*	Contrasts**
Physical frailty tests								
Barthel Index (AU)	Baseline	73.41 (2.35)	(68.67,78.15)	70.79 (2.53)	(65.69,75.89)	Group*Time	<.001	Baseline - week 12; p<.001
	Week 12	79.32 (2.35)	(74.58,84.06)	67.90 (2.53)	(62.79,73.0)			Baseline - week 36; p=.001
	Week 36	77.0 (2.38)	(72.19,81.80)	66.73 (2.73)	(61.26,72.21)			Week 12 - week 36; p=.049
Rapid gait test (s)	Baseline	11.73 (.60)	(10.52,12.93)	11.87 (.65)	(10.57,13.16)	Group*Time	<.001	Baseline - week 12; p<.001
	Week 12	9.20 (.60)	(7.99,10.41)	12.39 (.65)	(11.10,13.69)			Baseline - week 36; p<.001
	Week 36	10.05 (.62)	(8.82,11.29)	12.76 (.74)	(11.29,14.23)			Week 12 - week 36; p=.031
Stand up test (s)	Baseline	19.55 (.71)	(18.12,20.97)	17.05 (.93)	(15.16,18.93)	Group*Time	<.001	Baseline - week 12; p<.001
	Week 12	15.55 (.66)	(14.21,16.89)	17.93 (.92)	(16.07,19.79)			Baseline - week 36; p=.002
	Week 36	17.81 (.68)	(16.43,19.18)	17.47 (1.08)	(15.31,19.63)			Week 12 - week 36; p<.001

Note: Means and standard deviations are reported for each primary outcome measure at baseline and at week 12 and week 36 until completion of the study. Means were generated using participants with data at least two time points for the outcome of interest. P-values are based on linear mixed modelling.

*P-values are interpreted from the results of comparisons between specific time points. When the p-value interpreted is from the group-by-time interaction effect, the change between two time points for the two groups is compared.

**Bonferroni post-hoc tests were used with significant interactions (p < .05).

AU = arbitrary units; SD = standard deviation; CI = confidence interval.

Table 3. Secondary outcome measures (measures of balance, gait, MTGUG and strength).

Variable	Interval	FCT (n = 22)		Control (n = 19)				
		Mean (SD)	95% CI	Mean (SD)	95% CI	Effect tested	p-value*	Contrasts**
Balance								
ST (s)	Baseline	6.67 (.63)	(5.41,7.93)	7.26 (.68)	(5.91,8.62)	Group*Time	.01	Baseline - week 12; p<.001
	Week 12	9.27 (.63)	(8.01,10.53)	6.23 (.68)	(4.88,7.59)			Baseline - week 36; p=.021
	Week 36	8.49 (.68)	(7.13,9.85)	4.34 (.97)	(2.42,6.26)			Week 12 - week 36; p=.696
T (s)	Baseline	3.21 (.67)	(1.86,4.56)	3.11 (.73)	(1.66,4.56)	Group*Time	.003	Baseline - week 12; p<.001
	Week 12	6.60 (.67)	(5.25,7.95)	1.98 (.73)	(0.52,3.43)			Baseline - week 36; p=.001
	Week 36	5.40 (.72)	(3.97,6.83)	1.64 (.96)	(0.26,3.55)			Week 12 - week 36; p=.131
US (s)	Baseline	2.39 (.57)	(1.25,3.53)	2.05 (.62)	(.82,3.27)	Group*Time	<.001	Baseline - week 12; p<.001
	Week 12	6.60 (.57)	(5.46,7.74)	1.98 (.62)	(.75,3.20)			Baseline - week 36; p=.953
	Week 36	3.10 (.64)	(1.83,4.36)	.38 (.65)	(-1.51,2.27)			Week 12 - week 36; p<.001
Gait								
NGS (m/s)	Baseline	.82 (.04)	(.75,.90)	.82 (.04)	(.74,.91)	Group*Time	<.001	Baseline - week 12; p<.001
	Week 12	.94 (.04)	(.86,1.01)	.80 (.04)	(.72,.88)			Baseline - week 36; p=.003
	Week 36	.88 (.04)	(.80,.95)	.81 (.04)	(.72,.89)			Week 12 - week 36; p=.002
FGS (m/s)	Baseline	1.11 (.06)	(1.0,1.22)	1.13 (.06)	(1.01,1.26)	Group*Time	<.001	Baseline - week 12; p<.001
	Week 12	1.28 (.06)	(1.17,1.39)	1.07 (.06)	(.95,1.20)			Baseline - week 36; p<.001
	Week 36	1.23 (.06)	(1.11,1.34)	1.08 (.07)	(.95,1.21)			Week 12 - week 36; p=.064

MTGUG								
AQ (AU)	Baseline	9.32 (.40)	(8.51,10.13)	8.63 (.44)	(7.76,9.50)	Group*Time	<.001	Baseline - week 12; p<.001
	Week 12	11.82 (.40)	(11.01,12.63)	8.37 (.44)	(7.50,9.24)			Baseline - week 36; p=.009
	Week 36	10.28 (.42)	(9.43,11.13)	8.37 (.55)	(7.28,9.47)			Week 12 - week 36; p<.001
TT (s)	Baseline	38.04 (1.32)	(32.38,37.71)	39.34 (1.42)	(38.47,44.21)	Group*Time	<.001	Baseline - week 12; p<.001
	Week 12	35.04 (1.32)	(32.38,37.71)	41.34 (1.42)	(38.47,44.21)			Baseline - week 36; p=.01
	Week 36	37.50 (1.32)	(34.83,40.17)	41.95 (1.44)	(38.05,43.86)			Week 12 - week 36; p<.001
SU (s)	Baseline	2.59 (.17)	(2.26,2.92)	2.91 (.18)	(2.56,3.27)	Group*Time	.001	Baseline - week 12; p=.001
	Week 12	2.02 (.17)	(1.69,2.35)	3.18 (.18)	(2.83,3.54)			Baseline - week 36; p=1.0
	Week 36	2.55 (.18)	(2.20,2.91)	3.44 (.25)	(2.95,3.93)			Week 12 - week 36; p=.005
BT (s)	Baseline	3.0 (.28)	(2.43,3.57)	3.73 (.31)	(3.12,4.34)	Group*Time	.589	Baseline - week 12; p=.899
	Week 12	2.80 (.28)	(2.23,3.37)	3.82 (.31)	(3.21,4.43)			Baseline - week 36; p=1.0
	Week 36	2.97 (.30)	(2.38,3.57)	3.86 (38)	(3.10,4.62)			Week 12 - week 36; p=1.0
Kick-8m (s)	Baseline	14.76 (.80)	(13.15,16.37)	14.22 (.86)	(12.48,15.95)	Group*Time	<.001	Baseline - week 12; p<.001
	Week 12	12.27 (.80)	(10.66,13.88)	14.75 (.86)	(13.01,16.48)			Baseline - week 36; p=.077
	Week 36	13.90 (.81)	(12.26,15.54)	14.66 (.95)	(12.76,16.57)			Week 12 - week 36; p<.001
TT-kick (s)	Baseline	24.28 (.83)	(22.61,25.95)	25.44 (.89)	(23.64,27.24)	Group*Time	<.001	Baseline - week 12; p=.001
	Week 12	22.77 (.83)	(21.10,24.44)	26.59 (.89)	(24.79,28.39)			Baseline - week 36; p=.130
Isom. dynamometry	Week 36	23.40 (.85)	(21.70,25.11)	26.27 (1.01)	(24.26,28.28)			Week 12 - week 36; p=.424
adjusted for body mass								
LKEMVC (Nm/kg)	Baseline	.77 (.06)	(.65,.88)	.75 (.06)	(.63,.88)	Group*Time	<.001	Baseline - week 12; p<.001
	Week 12	.92 (.06)	(.80,1.03)	.71 (.06)	(.58,.83)			Baseline - week 36; p=.46
	Week 36	.82 (.06)	(.70,.94)	.61 (.07)	(.47,.76)			Week 12 - week 36; p=.031

Note: Means and standard deviations are reported for each secondary outcome measure at baseline and at week 12 and week 36 until completion of the study. Means were generated using participants with data at least two time points for the outcome of interest. P-values are based on linear mixed modelling.

*P-values are interpreted from the results of comparisons between specific time points. When the p-value interpreted is from the group-by-time interaction effect, the change between two time points for the two groups is compared.

**Bonferroni post-hoc tests were used with significant interactions ($p < .05$).

AU = arbitrary units; SD = standard deviation; CI = confidence interval.

Figure 1. Flowchart of participant's recruitment and trial design (CONSORT)

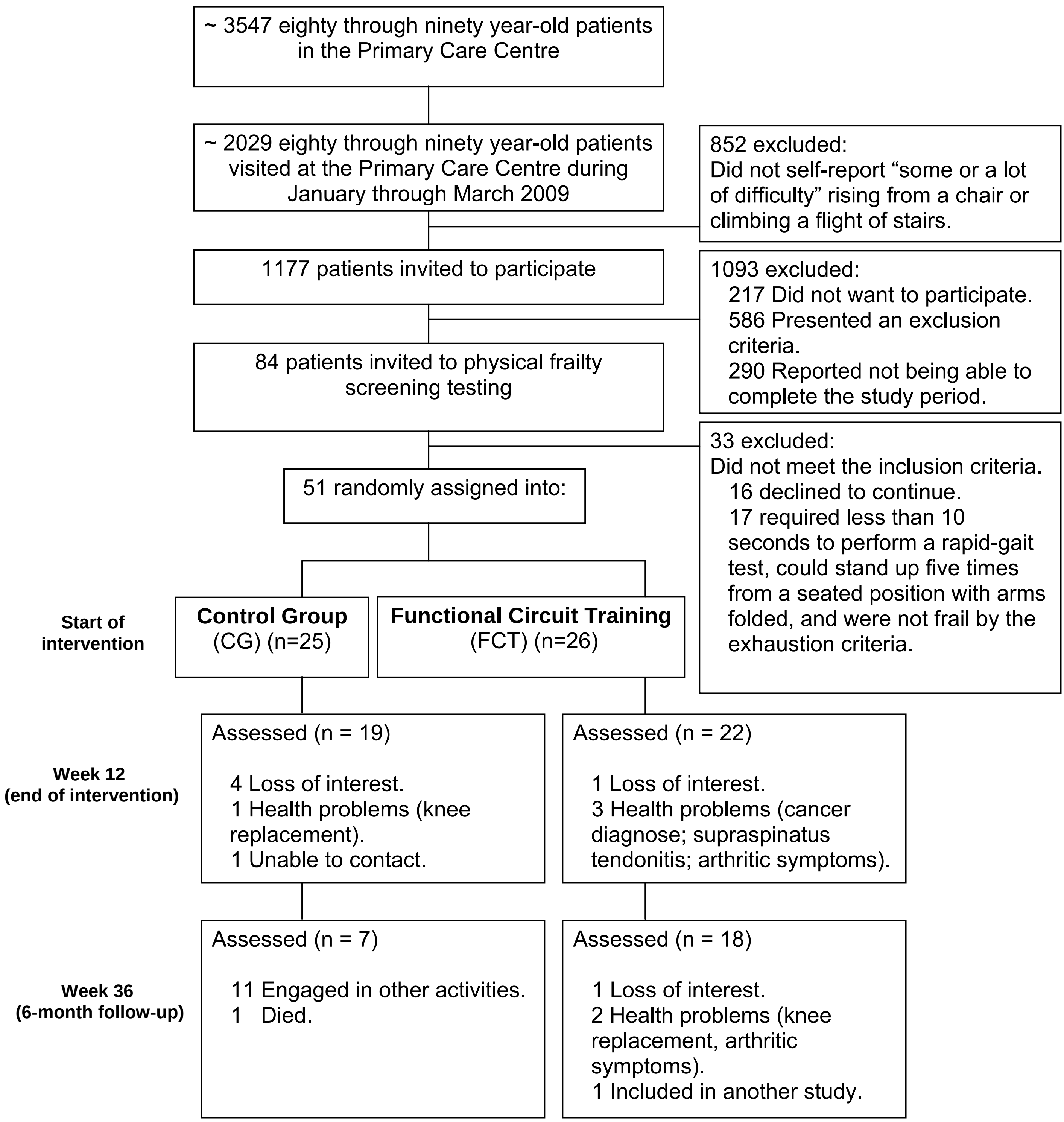


Figure 2a. Changes in the Barthel index score from week 0 (baseline) to end of the study.

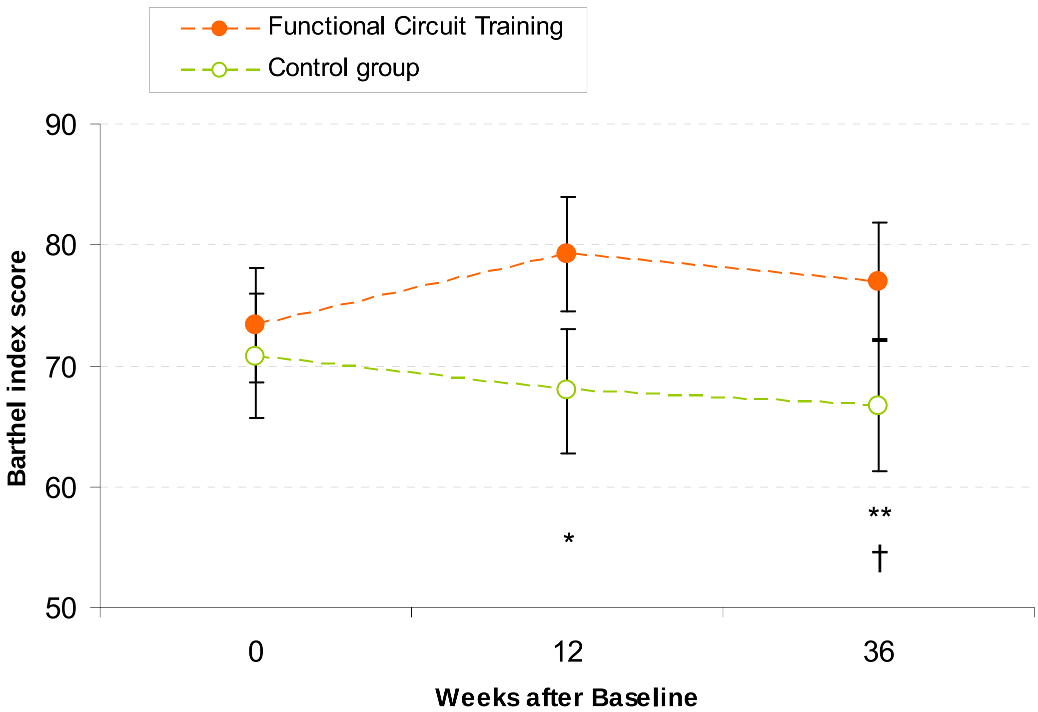


Figure 2b. Changes in the rapid gait test score from week 0 (baseline) to end of the study.

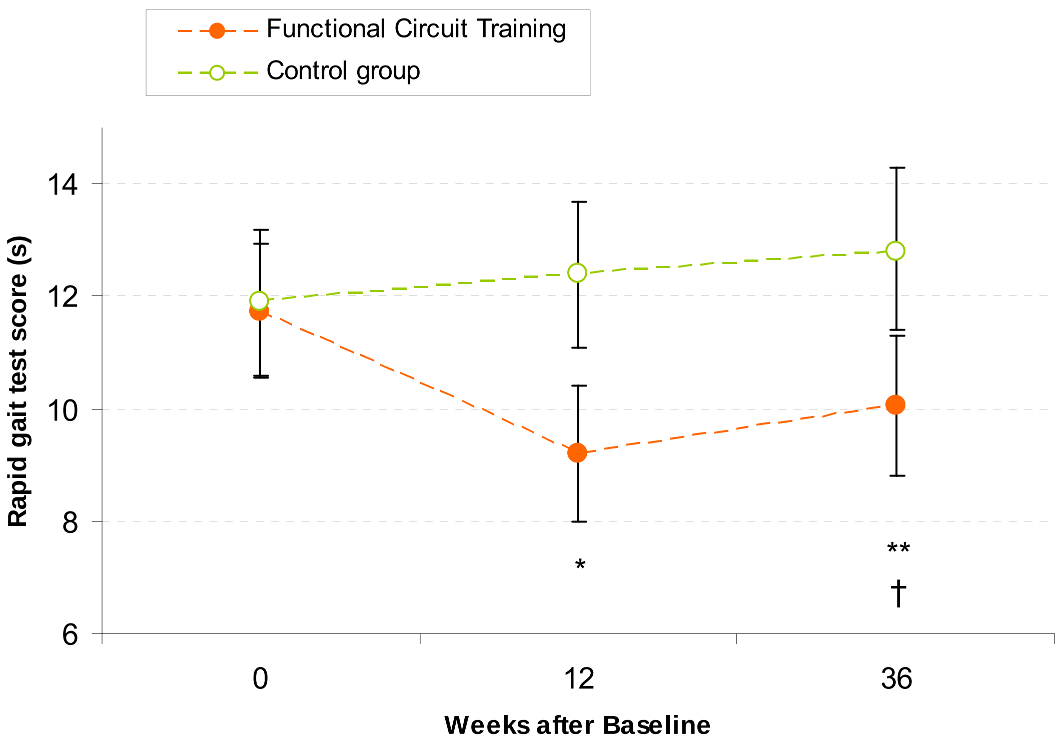
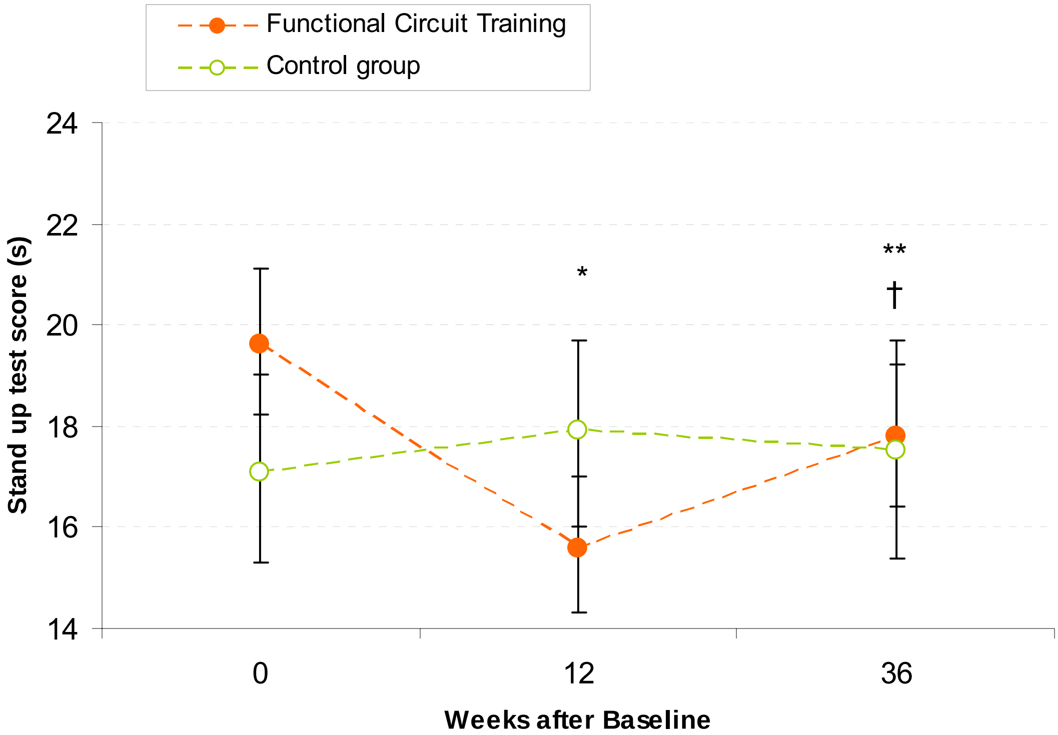


Figure 2c. Changes in the stand up test score from week 0 (baseline) to end of the study.



Note: Values are means and standard deviations. Significant group-by-time interactions were noted ($p < .05$).

*Baseline to week 12 interaction.

**Baseline to week 36 interaction.

†Week 12 to week 36 interaction.

5. GENERAL DISCUSSION

5.1 Reliability and construct validity of the modified TGUG test

Based on the evidence from the first study, it can be stated that the modified TGUG test demonstrated good sensitivity and good inter-tester reliability from both a quantitative and qualitative perspective. Moreover, evidence from the second study showed that the correlations between the MTGUG test and comparison tests, including dynamometry testing, were moderately strong and statistically significant. The data from the second study provided information to support concurrent criterion validity. It has been demonstrated in the literature that construct validity can be established by correlating a new test instrument with validated, clinically accepted tests (Doménech, 2006). Specifically, the second study showed that (i) TT, kick 8 m, and TT-kick 8 m measures were significantly correlated to normal and fast gait speed, (ii) SU and BT were significantly correlated to five chair rises and right knee extensor MVC, and (iii) the total points obtained in the AQ significantly correlated to the single-leg balance measures and POMA scale.

Physical function assessment is not standardized within or across hospital, nursing home, or community-dwelling settings. A number of physical performance screening tests have been found to be reliable and valid to assess functional decline amongst people living in residential homes (Berg et al., 1992; Podsiadlo & Richardson, 1991; Tinetti, 1986; Whitney et al., 2000), however, these same tests have proven to be less accurate amongst senior citizens who live independently (Boulgarides et al., 2003; Mathias et al., 1986; Whitney et al., 2000). These and other measures have been shown to predict outcomes such as falls, institutionalization, and death (Berg et al., 1992; Boulgarides et al., 2003; Duncan et al., 1992; Guralnik et al., 1994; Lord & Fitzpatrick, 2001; Medell & Alexander, 2000; Perell et al., 2001; Shumway-Cook et al., 2007; Tinetti, 1986; Tinetti et al., 1988; Wall et al., 2000; Whitney et al., 2000). Furthermore, these tests do not assess physical performance other than gait and balance (Berg et al., 1992; Boulgarides et al., 2003; Perell et al., 2001; Tinetti, 1986; Wall et al., 2000; Whitney et al., 2000), or only balance (Duncan et al., 1992; Medell & Alexander, 2000), reaction time (Lord & Fitzpatrick, 2001), lower extremity function (Guralnik et al., 1994; Guralnik et al., 1995), and gait through complex walking tasks (Shumway-Cook et al., 2007).

Data on inter-rater reliability had been provided for the majority of the functional assessment tools mentioned above, and ranged from 58% to 98% across the various functional assessment tools. Information on predictive validity had been included for all the functional assessment studies. Despite the good inter-rater reliability and predictive validity, the majority of these tests were developed mainly in hospital or nursing home settings (Berg et al., 1992; Podsiadlo & Richardson, 1991; Tinetti, 1986).

Based on the first study, data from the one-way ANOVA showed no significant differences between Groups 2 (sedentary subjects with no previous history of falls) and 3 (active subjects with a previous history of falls) neither for TT nor AQ. Therefore, it appears that being active conferred no significant advantage to the individual, if that individual had a previous history of falls. It has been largely discussed that a previous history of falls usually results in a psychological effect named fear of falling, leading to reduced daily activities (Tinetti et al., 1990) and patient's loss of confidence in his or her balance abilities (Powell & Myers, 1995), with subsequent losses in physical capabilities. The test appeared to have good discriminating powers with respect to the total time to complete de test (TT), as differences were evident between Groups 1 (sedentary subjects who had at least one fall in the previous 6 months) and 2 (sedentary subjects with no previous history of falls) and between Group 4 (active subjects with no previous history of falls) and the other groups. AQ did not demonstrate the same sensitivity as TT, AQ was only capable of discriminating between individuals of very low function (Group 1) and the other groups. Considering the number of elderly individuals in the general population that lay in Groups 2-4, the utility of the AQ test needs to be challenged. Preventive interventions might be then needed in reducing the risk of falling.

According to the second study, the total time to complete the test (TT, includes both cognitive and physical dual-task), the time taken to kick the ball and walk pass the 8-m line (kick-8 m line, dual-task: cognitive task while walking), and the time taken from crossing the 8 m line and return to the chair (TT-kick 8 m, dual-task: physical task while walking) demonstrated higher inverse correlations with normal gait speed than fast speed, thus indicating the importance of assessing older people's performance at their usual pace. Montero-Odasso et al. (2005) found that the usual gait speed measurement could allow the detection of healthy elderly people at risk for adverse events. It has been previously demonstrated that walking at a fast pace might mask gait patterns and balance impairments in the elderly (Shumway-Cook et al., 2007). Therefore, subjects were asked to perform the MTGUG test at their usual pace.

Moreover, the second study demonstrated a higher inverse correlation between gait speed and the kick 8 m (cognitive task while walking) than between gait speed and TT-kick 8 m (physical task while walking). Assuming that reduced gait speed has been associated to functional decline (Guralnik et al., 1994, Guralnik et al., 1995), the implications of these findings are that counting backwards while walking is a more sensitive way to assess functional decline than a physical task such as stepping into circles while walking, included in the MTGUG test. However, the best predictor of normal gait speed was TT, thus validating the use of both a cognitive and a physical dual task in the MTGUG test.

It has been previously demonstrated that dual tasks result in diminished gait performance (Armieri et al., 2008; Beauchet et al. 2008). Dubost et al. (2006) reported increased gait variability in healthy older adults who performed simple arithmetical tasks; and Lindenberger et al. (2000) demonstrated that the dual task demands increased with aging, especially when walking through a complex course (i.e., reduction in gait speed, increased number of missteps when walking over a narrow route, as well as reduction in performance of the cognitive task). By assessing the relationship between gait speed and kick 8 m (cognitive task while walking) and TT-kick 8 m (physical task while walking) respectively, we wanted to establish criterion validity of the dual task component with both a cognitive and physical task respectively in the MTGUG. These type of activities mimic physical processes that are encountered in a usual day and represents the real utility of the test. Shumnway-Cook et al. (2000), however, concluded that the ability to predict falls was not enhanced by adding a secondary task when performing the TGUG, although the ability to predict functional decline as predictor of future falls in some populations of elderly individuals was not reported.

Inverse correlation between the stand up (SU) of the MTGUG test, and right knee extensor MVC were moderately strong, at least as strong as other standard measures (Daubney & Culham, 1999; Medell & Alexander, 2000). A sit-to-stand movement requires muscle strength greater than other daily activities, such as walking or stair climbing (Ploutz-Snyder et al., 2002). Similarly, Lord et al. (2002) demonstrated that in community-dwelling older people during a sit-to-stand performance, quadriceps strength was the most important variable in explaining the variance in sit-to-stand times (Lord et al., 2002). As shown in the second study, sufficient leg extension strength is required for being able to stand up from a chair (Aagaard et al., 2007) and for adequate balance recovery after a gait perturbation (Pavol et al., 2002; Shumway-Cook et al., 2007). Correlation between ball time (BT) of the MTGUG and knee extensor MVC also showed an inverse relationship, but were not as high as SU, however, they were statistically significant. A previous study demonstrated that the ball velocity significantly correlated with the knee extensor muscular strength of the kicking leg at a given approach angle (Masuda et al., 2005).

The data from the second study suggest that timed performance is important and has been used to successfully evaluate functional limitation. However, when attempting to quantify how older adults perform each task (in terms of quality of performance), timed performance suffers at the expense of the accuracy of the task performed. Total timed performance and the items assessed in the assessment questionnaire were significantly correlated (r = -0.564), but the explained variance was low. Therefore, data obtained with both studies showed that timed performance is a more valid measure than the assessment questionnaire (AQ) to document physical function.

Even though AQ measures showed a positive relationship and correlated significantly to SLB and POMA measures, SLB showed weak correlation with TT, SU, BT and kick-8 m. This could have been because SLB measures were mainly related to balance, and the other measures included in the MTGUG test, despite involving the need for postural balance, do not specifically assess it. The data from the second study contradicts the work of Cho et al. (2004) who found higher significant correlation of SLB measures to the TGUG test, probably due to lower functional impairment in their sample population.

5.2 Functional circuit training program

The two major findings of this study were that: (1) a functional circuit training program that focused on functional balance and lower body strength-based exercises (FCT) was effective in improving performance in physical measures, which led to a reduction in markers of physical frailty in community-dwelling frail older adults, and (2) these improvements were sustained in selected variables 6 months after the end of the training program.

The stimulus of the FCT induced improvements in all physical frailty measurements at week 12. These were: the Barthel index score, the rapid-gait test and the stand-up test, which focused on functional tasks used in everyday activities. The importance of incorporating functional exercises when designing an intervention aiming to improve physical function in frail older adults had been documented in previous studies (Ferrucci et al., 2004; Manini et al., 2007; Skelton & McLaughlin 1996). The functional exercises included in our program were specifically designed to mimic everyday tasks; even though some exercises were slightly similar, they were not identical to the outcome measures. Given the principle of specificity of training (Brooks et al., 2000), improvements in function could be explained by neuromuscular adaptations in neural control of movement, which are likely contributors to functional adaptations. These adaptations could potentially comprise of changes in the neural activation of muscles, with modifications occurring in both intramuscular and intermuscular coordination (Grabiner & Enoka, 1995). Such adaptations may include decreased antagonist coactivation (Carolan & Cafarelli, 1992), improved coordination of synergist muscles (Carolan & Cafarelli, 1992), increased neural drive to agonist muscles resulting in the recruitment of additional motor units (Akima et al., 1999), and increased motor unit firing rates (Patten, Kamen & Rowland, 2001).

The improvements in physical frailty measurements (Barthel index score, rapid-gait test, and the stand-up test) were sustained 6 months after the training ended. A possible mechanism for this sustainability is that neural adaptations caused by training seem to be maintained for longer periods of time than strength related gains (de Vreede et al., 2005). The motor learning that occurs during training results in a consolidation of the patterns of intermuscular and intramuscular coordination that are specific to the particular movements performed repetitively throughout training (de Vreede et al., 2005). The effectiveness with which these adaptations transfer to related movements depends on the similarity between those muscle activation patterns consolidated through the regular performance of the training exercise and those required during different movement tasks. Skelton et al. (1995) aimed to assess the effects of a 12-week intervention designed to specifically strengthen the muscles considered relevant for the functional tasks but without mimicking functional measurements. These authors showed greater improvements in muscle strength than in functional abilities. Our week 36 follow-up measures of physical frailty extend the evidence about the importance of the exercise being task specific if functional ability is to be improved.

The training program used in study three demonstrated significant improvements in balance and gait measures in the FCT compared to the CG at week 12. Nelson et al. (2004) suggested that improvements in physical performance (e.g. strength, gait speed and cardiovascular endurance) tend to occur along with those occurring in balance. Data from the third study are in agreement with previous training programs that have shown improvements in gait speed and balance performance in an elderly population

(Fiatarone et al., 1994; Islam et al., 2004). Semi-tandem and tandem stance values were still above baseline 6 months after the cessation of the training program. The single-leg stance measure, however, showed a reversibility of single-leg balance gains by week 36. The main difference between single-leg stance and the other balance measures assessed in the present study is that the single-leg stance places a greater demand on the quadriceps and hip flexor and extensor muscles (Daubney & Culham, 1999). Consequently, the reversibility in the gains made in the single-leg stance could be linked to the inability to maintain selected strength measurements 6 months after the end of training. Evidence exists in the literature to suggest that strength gains may be maintained between 5 to 27 weeks after cessation of training in older adults (Fatouros et al., 2005; Lemmer et al., 2000). As shown by Fatouros et al. (2005), all training induced gains in strength were abolished after 4 to 8 months after training ceased.

Furthermore, normal and fast gait speed also showed significant improvements from baseline to the week 36 follow-up. This finding is in disagreement with Lopopolo et al.'s review (2006), which concluded that exercise influences only slow walking speed in elderly people. Perhaps, due to the specificity of training principle, FGS would be expected to improve when step cadence and frequency of stepping was specifically trained, as occurred in the third study.

Physical function assessed with the MTGUG test improved in all variables except for the ball time measure in the week 12 assessment. The MTGUG test measures balance and gait with a dual-task. With normal aging, structural changes of the brain occur, especially in the prefrontal areas, regions that have been associated with the executive function and attentional systems (Charlton et al., 2006). The improvement in the performance of two attention-demanding tasks could be also explained by neuromuscular adaptations in neural control of movement given the principle of specificity of training (Brooks et al., 2000) stated earlier in the discussion. Ball time (BT) of the MTGUG did not demonstrate any improvement in week 12 measures compared to baseline, probably because the training study did not specifically include a kicking task. The TT and the AQ measurements were sustained at the week 36 follow-up. However, the stand up, kick - 8m, and TT- Kick 8m measures in the MTGUG test showed a reversibility of training effects at week 36 follow-up back to week 0 measures. The stand up test in the physical frailty measures showed a significant improvement at week 36 follow-up. The main difference between both tests is that the stand-up test assesses muscular quadriceps endurance, and the SU of the MTGUG assesses mainly muscular quadriceps strength and reaction time. As shown in previous research, long term sustainability of strength gains is quite difficult to achieve (Fatouros et al., 2005; Lemmer et al., 2000), and the FCT didn't specifically train reaction time.

With respect to the dynamometry testing, left knee extensor isometric strength was the only measure which improved at week 12 measures. In our study population, most of the subjects were right leg dominant (73%), therefore, there was a greater capacity for improvement in the left lower extremities due to the lower starting point (Fiatarone et al., 1994, Hubbard et al., 2009). Furthermore, the specificity of the FCT program led to a greater stimulus for increased extensor muscle strength (e.g. rising from a chair, stair climbing, leg extension). There was not a sustainability of the left knee extensor strength gains in week 36 follow-up. As stated previously, decrements in strength occur quite rapidly following the cessation of training (Fatouros et al., 2005; Lemmer et al., 2000). Moreover, FCT aimed to improve function rather than isometric strength, thus, it is plausible that impairments limiting muscular strength did not change because the exercises were of insufficient intensity to produce gains in this domain. The non-significant improvement of strength over time may also reflect age-related changes in this population. If muscular strength was to be improved, the training program design would need to focus on specific resistance training (Skelton et al., 1995).

6. CONCLUSIONS

The implications of the findings from the first study suggest that the modified TGUG test for total time (sec) may be suitable to discriminate older individuals of high and low functional levels. Based on the data from the one-way ANOVA, no significant differences were noted between Group 2 and 3 neither for TT nor AQ. Therefore, it appears that being active conferred no significant advantage to the individual, if that individual had a previous history of falls. The test appeared to have good discriminating powers with respect to TT, as differences were evident between Groups 1 and 2 and between Group 4 and the other groups. AQ did not demonstrate the same sensitivity as TT, AQ was only capable of discriminating between individuals of very low function (Group 1) and the other groups. Considering the number of elderly individuals in the general population that lay in Groups 2-4, the utility of the AQ test, therefore, needs to be challenged.

Furthermore, based on the strength of the correlations obtained between components of the modified TGUG and the comparison tests, concurrent, criterion validity of the modified TGUG has been indicated. The test is simple to administer, needs a short administration time, and is feasible for older people to undertake in community settings and for rehabilitation assessment in primary care.

The functional circuit training program assessed in the third study, was tolerated well by participants, is a short, low-tech and low-cost form of exercise and, therefore, potentially suitable for clinical settings and primary care centers. In summary, our findings indicate that a 12-week FCT program which focused on functional balance, and lower body strength-based exercises, conducted in a primary care setting is a safe, effective and sustainable intervention in older physically frail community-dwelling adults. The program led to fewer functional limitations and reduced physical impairments, leading to a reduction in physical frailty parameters, which were maintained 6 months after the cessation of training. This type of intervention may help in the prevention or postponement of frailty that is severe enough to cause loss of independence.

In conclusion, the elderly population require an appropriate physical function screening assessment, and specific proven interventions need to be put in place to maximize physical functioning once the deficit areas are known. A simple screening procedure linked with effective public health interventions may offer great scope for reducing functional decline in at-risk older people.

Future directions for research

1. Further work is required to identify the most effective exercise interventions for improving physical functioning depending on the population's physical performance. Although there is sufficient evidence to encourage increased physical activity for the public and most patient groups, multiple aspects of physical activity and health warrant additional investigation.
2. Similar information on factors influencing the adoption and maintenance of physical activity is required for older adults. In particular, there is a need to focus on physical activity promotion efforts via organizational (eg, work sites and communities) and legislative policy changes, rather than just on the individual level. There is no doubt that as the older population comprises a diverse group in relation to physical functioning, there will be no single exercise prescription for this group. Specific studies are required to identify exercise components that are effective in maintaining strength, coordination, and balance and the ability to carry out functional activities in both the more vigorous, independent older population and in frailer groups. Finally, cost-effectiveness studies are needed to evaluate the role of physical activity relative to other interventions on healthcare costs.
3. Exercise studies also need to be conducted as public health interventions, not just as demonstration projects, to identify programs that are acceptable to older people in the long term. It seems important that the interventions involved in a group exercise program are of sufficient intensity to significantly improve physical function. Such work should also address strategies for overcoming barriers to exercise participation and adherence.
4. It would be important to identify the underpinning physiological mechanisms responsible for the improvements seen in balance and gait as a result of training.
5. It would be of interest to investigate how the exercises included in the functional circuit training program designed for the third study, contribute to functional adaptations. This could be achieved by looking at changes in the neural activation of muscles (e.g. decreased antagonist co-activation, improved coordination of synergist muscles, increased neural drive to antagonist muscles resulting in the recruitment of additional motor units, and increased motor unit firing rates).

7. SUMMARY (Catalan version)

Resum del primer estudi

L'objectiu de l'estudi va ser avaluar la fiabilitat d'un versió modificada del test *Timed Get Up and Go* (MTGUG) per predir el risc de caigudes en gent gran, emprant una aproximació quantitativa i qualitativa en persones majors de 65 anys.

Mètode. Deu subjectes (83.4 ± 4.5 anys) varen realitzar el test dues vegades. Per avaluar la fiabilitat inter-jutge, tres investigadors varen cronometrar els dos intents utilitzant un cronòmetre (aproximació quantitativa). La fiabilitat de l'aproximació qualitativa d'ambdós intents es va fer completant un qüestionari d'avaluació (AQ) pels mateixos tres investigadors. Per avaluar el grau d'acord entre els tres investigadors en el temps total per realitzar el test (TT), es varen determinar els coeficients de fiabilitat (CR), els coeficients de correlació intra-classe (ICC), i els límits d'acord. El factor kappa K de Cohen i els ICC es varen calcular per l'AQ.

Resultats. *Comparació inter-jutge.* 60 subjectes (74.2 ± 4.9 anys) es varen dividir igualitàriament en quatre grups: (1) 15 subjectes sedentaris amb història prèvia de caigudes, (2) 15 subjectes sedentaris sense història prèvia de caigudes, (3) 15 subjectes actius amb història prèvia de caigudes, i (4) 15 subjectes actius sense història prèvia de caigudes. Tots varen realitzar el test MTGUG una vegada. Tres investigadors varen cronometrar el temps de la prova i varen completar l'AQ. Els valors dels CR pel TT foren superiors al 98% amb un ICC de TT = 0.999. Les diferències en el TT entre les mesures dels tres investigadors foren de 0.19-0.55 segons de la desviació estàndard de la diferència mitjana. El factor kappa K de Cohen va ser de 0.835-0.976, amb un ICC de l'AQ = 0.954. *Comparació inter-grup*. Es varen demostrar diferències significatives ($p < 0.05$) entre el resultat mitjà de TT del grup 4 i la resta de grups, i entre el grup 2 i el grup 1. Es varen demostrar també diferències significatives ($p < 0.05$) de la mitjana de punts obtinguts a l'AQ entre el grup 1 i la resta de grups.

Conclusions. La versió modificada del test TGUG va demostrar una bona sensibilitat per detectar el risc de caigudes en gent gran, i una bona fiabilitat inter-jutge des d'una perspectiva quantitativa i qualitativa.

Resum del segon estudi

L'objectiu del segon estudi va ser determinar el grau d'associació entre els resultats obtinguts al test MTGUG i altres mesures d'avaluació funcional física.

Mètode. Trenta set dones grans residents a la comunitat (72.3 ± 5.5 anys) es varen oferir voluntàries per participar en l'estudi. Es va avaluar a tots els participants realitzant el test MTGUG. Es varen establir comparacions entre el test MTGUG i el test de mobilitat de Tinetti, la prova de l'estació unipodal, aixecar-se 5 vegades de la cadira, la prova de velocitat de marxa normal i ràpida, i la força isomètrica de flexors i extensors de genoll.

Resultats. El temps total per desenvolupar el test MTGUG es va correlacionar significativament amb la prova de velocitat de marxa normal i ràpida ($p < 0.05$). El coeficient de correlació de Pearson va ser -0.841 i -0.748 respectivament. El temps requerit per desenvolupar diferents tasques del test MTGUG es va relacionar significativament amb aixecar-se 5 vegades de la cadira, i amb la força isomètrica dels extensors del genoll dret ($p < 0.05$). Els punts obtinguts a l'AQ es varen correlacionar significativament amb als punts obtinguts al test de mobilitat de Tinetti ($p < 0.05$). El coeficient de correlació de Pearson va ser 0.795.

Conclusions. S'ha establert la validació de la versió modificada del test Timed Get Up and Go (MTGUG) d'acord amb les correlacions fortes i significatives obtingudes entre el test MTGUG i els altres tests.

Resum del tercer estudi

L'objectiu del tercer estudi va ser avaluar si un programa de 12 setmanes basat en un treball funcional d'equilibri i força de les extremitats inferiors (FCT) podia alterar els indicadors físics de fragilitat en un grup d'individus entre 80 i 90 anys fràgils residents a la comunitat.

Mètode. Cinquanta un individus (31 dones, 20 homes), de 84 ± 2.9 anys, que complien els criteris de fragilitat establerts, varen ser aleatoritzats en dos grups (FCT=26, grup control, CG=25). FCT varen realitzar un programa d'exercici de 12 setmanes (2 sessions/setmana de 45 minuts/sessió). El CG es va reunir un cop/setmana per sessions d'educació sanitària. Es varen avaluar mesures de fragilitat, funcionalitat física, força, equilibri, i velocitat de marxa, a l'inici del programa (setmana 0), al final del programa (setmana 12), i passats 6 mesos de la finalització del programa (setmana 36).

Resultats. Les mesures de fragilitat en el grup FCT varen demostrar millores significatives en relació al CG (els resultats de l'índex de Barthel a la setmana 0 i 36: 73.41 ± 2.35 and 77.0 ± 2.38 en el FCT i 70.79 ± 2.53 i 66.73 ± 2.73 en el CG).

Conclusions. Els resultats obtinguts en el present estudi indiquen que el programa FCT és efectiu per millorar les mesures de funcionalitat física i reduir la fragilitat física en individus grans fràgils.

8. REFERENCES

Aagaard P, Magnusson PS, Larsson B, Kjaer M, & Krustrup P. Mechanical muscle function, morphology, and fiber type in lifelong trained elderly. *Med Sci Sports Exerc* 2007;39:1989-1996.

Aagaard P, Simonsen EB, Andersen JL, Magnusson P, & Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol* 2002;93:1318-1326.

Abrams WB, & Berkow R. *El manual Merck de Geriatría*. Madrid: Doyma, 1990.

Akima H, Takahashi H, Kuno SY, Masuda K, Masuda T, Shimojo H, Anno I, Itai Y, & Katsuta S. Early phase adaptations of muscle use and strength to isokinetic training. *Med Sci Sports Exerc* 1999;31:588-594.

Amblard B, Crémieux J, Marchand AR, & Carblanc A. Lateral orientation and stabilization of human stance: static versus dynamic visual cues. *Exp Brain Res* 1985;61:21-37.

American Geriatrics Society, British Geriatrics Society, & American Academy of Orthopaedic Surgeons Panel on Falls Prevention. Guidelines for the prevention of falls in older persons. *J Am Geriatr Soc* 2001;49:664-672.

Aniansson A, Sperling L, Rundgren A, & Lehnberg E. Muscle function in 75-year-old men and women. A longitudinal study. *Scand J Rehabil Med Suppl* 1983;9:92-102.

Aniansson A, Zetterberg C, Hedberg M, & Henriksson KG. Impaired muscle function with aging. A background factor in the incidence of fractures of the proximal end of the femur. *Clin Orthop Relat Res* 1984;191:193-201.

Armieri A, Holmes JD, Spaulding SJ, Jenkins ME, & Johnson AM. Dual task performance in a healthy young adult population: results from a symmetric manipulation of task complexity and articulation. *Gait Posture* 2009;29:346-348.

Atkinson G, & Nevill AM. Statistical methods for assessing measurements error (reliability) in sports medicine. *Sports Med* 1998;26:217-238.

Baker SP, & Harvey AH. Fall injuries in the elderly. *Clin Geriatr Med* 1985;1:501-512.

Baloh RW, Corona S, Jacobson KM, Enrietto JA, & Bell T. A prospective study of posturography in normal older people. *J Am Geriatr Soc* 1998;46:438-443.

Bartual J. Anatomía y fisiología del sistema vestibular periférico. In: Bartual J, Pérez N, editors. *El sistema vestibular y sus alteraciones*. Barcelona: Biblio stm, 1998:21-52.

Bayles C. Frailty. In: ACSM, editor. *ACSM's exercise management for persons with chronic diseases and disabilities*. Champaign, Ill: Human Kinetics, 1997:112-118.

Bean JF, Herman S, Kiely DK, Frey IC, Leveille SG, Fielding RA, & Frontera WR. Increased Velocity Exercise Specific to Task (InVEST) training: a pilot study exploring effects on leg power, balance, and mobility in community-dwelling older women. *J Am Geriatr Soc* 2004;52:799-804.

Beauchet O, Annweiler C, Allali G, Berrut G, Herrmann FR, & Dubost V. Recurrent falls and dual task-related decrease in walking speed: is there a relationship? *J Am Geriatr Soc* 2008;56:1265-1269.

Becker C, Kron M, Lindemann U, Sturm E, Eichner B, Walter-Jung B, & Nikolaus T. Effectiveness of a multifaceted intervention on falls in nursing home residents. *J Am Geriatr Soc* 2003;51:306-313.

Behrman AL, Light KE, Flynn SM, & Thigpen MT. Is the Functional Reach Test useful for identifying falls risk among individuals with Parkinson's disease? *Arch Phys Med Rehabil* 2002;83:538-542.

Ben-Shlomo Y, & Kuh D. A life course approach to chronic disease epidemiology: conceptual models, empirical challenges and interdisciplinary perspectives. *Int J Epidemiol* 2002;31:285-293.

Bentov M, Smith D, Siegal DL, & Doress PD. Envejecimiento y bienestar. In: Doress PB, Siegal DL, editors. *Envejecer juntas. Las mujeres y el paso del tiempo: datos para afrontarlo con optimismo, conocimiento de causa y decisión.* Barcelona: Paidós, 1993:23-44.

Berg K, Wood-Dauphinee S, Williams JI, & Gayton D. Measuring balance in the elderly: Preliminary development of an instrument. *Physiotherapy Canada* 1989;41:304-311.

Berg K, Wood-Dauphinee S, Williams JI, & Maki B. Measuring balance in the elderly: Validation of an instrument. *Can J Public Health* 1992;83(Suppl 2):S7-S11.

Bergland A, Jarnlo GB, & Laake K. Predictors of falls in the elderly by location. *Aging Clin Exp Res* 2003;15:43-50.

Bergman H, Ferrucci L, Guralnik J, Hogan DB, Hummel S, Karunananthan S, & Wolfson C. Frailty: An Emerging Research and Clinical Paradigm- Issues and Controversies. *J Gerontol A Biol Sci Med Sci* 2007;62A:M731-M737.

Beswick AD, Rees K, Dieppe P, Ayis S, Gooberman-Hill R, Horwood J, & Ebrahim S. Complex interventions to improve physical function and maintain independent living in elderly people: a systematic review and meta-analysis. *Lancet* 2008;371:725-735.

Betts LR, Sekuler AB, & Bennett PJ. The effects of aging on orientation discrimination. *Vision Res* 2007;47:1769-1780.

Billino J, Bremmer F, & Gegenfurtner KR. Differential aging of motion processing mechanisms: evidence against general perceptual decline. *Vision Res* 2008;48:1254-1261.

Binder EF, Schechtman KB, Ehsani AA, Steger-May K, Brown M, Sinacore DR, Yarasheski KE, & Holloszy JO. Effects of exercise training on frailty in community-dwelling older adults: results of a randomized, controlled trial. *J Am Geriatr Soc* 2002;50:1921-1928.

Birren JE, & Renner VJ. Research on the psychology of aging. Principles and experimentation. In: Birren JE, Shaie KW, editors. *Handbook of the Psychology of Aging.* New York: Van Nostrand, 1977:87-99.

Bischoff HA, Stähelin HB, Monsch AU, Iversen MD, Weyh A, von Dechend M, Akos R, Conzelmann M, Dick W, & Theiler R. Identifying a cut-off point for normal mobility: a comparison of the timed 'up and go' test in community dwelling and institutionalised elderly women. *Age Ageing* 2003;32:315-320.

Borg G. (1970). Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med* 1970;2:92-98.

Bortz WM. A conceptual framework of frailty: a review. *J Gerontol A Biol Sci Med Sci* 2002;57A:M283-M288.

Bosco C, & Komi PV. Influence of aging on the mechanical behaviour of leg extensor muscles. *Eur J Appl Physiol* 1980;45:209-219.

Boshuizen HC, Stemmerik L, Westhoff MH, & Hopman-Rock M. The effects of physical therapists' guidance on improvement in a strength training program for the frail elderly. *J Aging Phys Act* 2005;13:5-22.

Boulgarides LK, McGinty SM, Willett JA, & Barnes CW. Use of clinical and impairment-based tests to predict falls by community-dweeling older adults. *Phys Ther* 2003;83:328-339.

Brim OG, & Kagan J. *Constancy and Change in Human Development*. Cambridge, MA: Harvard University Press, 1980.

Brooke-Wavell K, Perrett LK, Howarth PA, & Haslam RA. Influence of the visual environment on the postural stability in healthy older women. *Gerontology* 2002;48:293-297.

Brooks GA, Fahey TD, White TP, & Baldwin KW. *Exercise physiology: Human bioenergetics and its applications*. New York: McGraw-Hill, 2000.

Brooks SV, & Faulkner JA. Skeletal muscle weakness in old age: underlying mechanisms. *Med Sci Sports Exerc* 1994;26:432-439.

Brown AP. Reducing falls in elderly people: A review of exercise interventions. *Physiother Theory Pract* 1999;15:56-68.

Brown LA, Shumway-Cook A, & Woollacott MH. Attentional demands and postural recovery: the effects of aging. *J Gerontol A Biol Sci Med Sci* 1999;54A:M165-M171.

Brown M, Sinacore DR, Ehsani AA, Binder EF, Holloszy JO, & Kohrt WM. Low-intensity exercise as a modifier of physical frailty in older adults. *Arch Phys Med Rehabil* 2000;8:960-965.

Buchner DM, Beresford SA, Larson EB, LaCroix AZ, & Wagner EH. Effects of physical activity on health status in older adults. II. Intervention studies. *Annu Rev Public Health* 1992;13:469-488.

Buchner DM, Cress ME, Esselman PC, Margherita AJ, de Lateur BJ, Campbell AJ, & Wagner EH. Factors associated with changes in gait speed in older adults. *J Gerontol* 1996a;51:M297-M302.

Buchner DM, Cress ME, de Lateur BJ, Esselman PC, Margherita AJ, Price R, & Wagner EH. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. *J Gerontol A Biol Sci Med Sci* 1997;52A:M218-M224.

Buchner DM, Hornbrook MC, Kutner NG, Tinetti ME, Ory MG, Mulrow CD, Schechtman KB, Gerety MB, Fiatarone MA, Wolf SL, et al. Development of the common data base for the FICSIT Trials. *J Am Geriatr Soc* 1993;41:297-308.

Buchner DM, Larson EB, Wagner EH, Koepsell TD, & de Lateur BJ. Evidence for a non-linear relationship between leg strength and gait speed. *Age Ageing* 1996b;25:386-391.

Buchner DM, & Wagner EH. Preventing frail health. *Clin Geriatr Med* 1992;8:1-17.

Bullock-Saxton JE, Janda V, & Bullock MI. Reflex activation of gluteal muscles in walking: an approach to restoration of muscle function for patients with low-back pain. *Spine* 1993;18:704-708.

Cairns RB, & Hood KE. Continuity in social development: a comparative perspective on individual difference prediction. In: Baltes PB, Brim OG Jr (eds). *Life Span Development and Behaviour.* New York: Academic Press, 1983:302-359.

Campbell AJ, Borrie MJ, & Spears GF. Risk factors for falls in a community-based prospective study of people 70 years and older. *J Gerontol A Biol Sci Med Sci* 1989;44A:M112-M117.

Campbell AJ, Borrie MJ, Spears GF, Jackson SL, Brown JS, & Fitzgerald JL. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. *Age ageing* 1990;19:136-141.

Campbell AJ, Robertson MC, Gardner MM, Norton RN, & Buchner DM. Psychotropic medication withdrawal and a home-based exercise program to prevent falls: A randomized, controlled trial. *J Am Geriatr Soc* 1999;47:850-853.

Campbell AJ, Robertson MC, Gardner MM, Norton RN, Tilyard MW, & Buchner DM. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. *BMJ* 1997;315:1065-1069.

Carnes BA, & Olshansky SJ. Heterogeneity and its biodemographic implications for longevity and mortality. *Exp Gerontol* 2001;36:419-430.

Carolan B, & Cafarelli E. Adaptations in coactivation after isometric resistance training. *J Appl Physiol* 1992;73:911-917.

Carter ND, Khan KM, McKay HA, Petit MA, Waterman C, Heinonen A, Janssen PA, Donaldson MG, Mallinson A, Riddell L, Kruse K, Prior JC, & Flicker L. Community-based exercise program reduces risk factors for falls in 65- to 75-year-old women with osteoporosis: randomized controlled trial. *CMAJ* 2002;167:997-1004.

Caspersen CJ, Powell KE, & Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep* 1985;100:126-131.

Cerny K, Blanks R, Mohamed O, Schwab D, Robinson B, Russo A, & Zizz C. The effect of a multidimensional exercise program on strength, range of motion, balance and gait in the well elderly. *Gait Posture* 1998;7:185-186.

Charlton RA, Barrick TR, McIntyre DJ, Shen Y, O'Sullivan M, Howe FA, Clark CA, Morris RG, & Markus HS. White matter damage on diffusion tensor imaging correlates with age-related cognitive decline. *Neurology* 2006;66:217-222.

Chin A Paw MJM, van Uffelen JG, Riphagen I, & van Mechelen W. The functional effects of physical exercise training in frail older people: a systematic review. *Sports Med* 2008;38:781-793.

Chiu AY, Au-Yeung SS, & Lo SK. A comparison of four functional tests in discriminating fallers from non-fallers in older people. *Disabil Rehabil* 2003;25:45-50.

Cho B, Scarpace D, & Alexander NB. Tests of stepping as indicators of mobility, balance, and fall risk in balance-impaired older adults. *J Am Geriatr Soc* 2004;52:1168-1173.

Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, & Skinner JS. American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc* 2009;41:1510-1530.

Chou LS, Kaufman KR, Hahn ME, & Brey RH. Medio-lateral motion of the centre of mass during obstacle crossing distinguishes elderly individuals with imbalance. *Gait Posture* 2003;18:125-133.

Ciccarelli J. *Generalitat de Catalunya.* Barcelona: Departament de Sanitat (online), 2003. Available at: www.prodig.yweb.net/rol. Accessed September 19, 2006.

Cnaan A, Laird NM, & Slasor P. Using the general linear mixed model to analyse unbalanced repeated measures and longitudinal data. *Stat Med* 1997;16:2349-2380.

Cohen HJ, Blatchly CA, & Gombash LL. A study of the Clinical Test of Sensory Interaction and Balance. *Phys Ther* 1993;73:346-354.

Cohen HJ, Feussner JR, Weinberger M, Carnes M, Hamdy RC, Hsieh F, Phibbs C, Courtney D, Lyles KW, May C, McMurtry C, Pennypacker L, Smith DM, Ainslie N, Hornick T, Brodkin K, & Lavori P. A controlled trial of inpatient and outpatient geriatric evaluation and management. *N Engl J Med* 2002;346:905-912.

Cornillon E, Blanchon MA, Ramboatsisetraina P, Braize C, Beauchet O, Dubost V, Blanc P, & Gonthier R. Effectiveness of falls prevention strategies for elderly subjects who live in the community with performance assessment of physical activities (before-after). *Ann Readapt Med Phys* 2002;45:493-504.

Craig CL, Marshall A, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, & Oja P. International Physical Activity Questionnaire: 12 country reliability and validity. *Med Sci Sports Exerc* 2003;35:1381-1395.

Cress ME, Buchner DM, Questad KA, Esselman PC, de Lateur BJ, & Schwartz RS. Exercise: effects on physical functional performance in independent older adults. *J Gerontol A Biol Sci Med Sci* 1999;54A:M242-M248.

Cryer C. *What works to prevent accidental injury amongst older people*. London: Health Development Agency, 2001.

Curb JD, Ceria-Ulep CD, Rodriguez BL, Grove J, Guralnik J, Willcox BJ, Donlon TA, Masaki KH, & Chen R. Performance-based measures of physical function for high-function populations. *J Am Geriatr Soc* 2006;54:737-742.

Daubney ME, & Culham EG. Lower-extremity muscle force and balance performance in adults aged 65 years and older. *Phys Ther* 1999;79:1177-1185.

Day L, Fildes B, Gordon I, Fitzharris M, Flamer H, & Lord S. Randomised factorial trial of falls prevention among older people living in their own homes. *BMJ* 2002;325:128-31.

Deiana L, Ferrucci L, Pes GM, Carru C, Delitala G, Ganau A, Mariotti S, Nieddu A, Pettinato S, Putzu P, Franceschi C, & Baggio G. AKEentAnnos. The Sardinia Study of Extreme Longevity. *Aging (Milano)* 1999;11:142-149.

DeMyer W. Examen de la sensibilidad somática (con exclusión de la cara). In: DeMyer W, editor. *Técnica del examen neurológico.* Buenos Aires: Editorial Médica Panamericana, 1987:373-408.

Dietz V. Afferent and efferent control of posture and gait. In: Bles W, Brandt T, editors. *Disorders of posture and gait.* Amsterdam: Elsevier, 1986:53-68.

Dite W, & Temple VA. A clinical test of stepping and change of direction to identify multiple falling older adults. *Arch Phys Med Rehabil* 2002;83:1566-1571.

Doherty TJ, Vanervoort AA, & Brown WF. Effects of ageing on the motor unit: a brief review. *Can J Appl Physiol* 1993;18:331-358.

Doménech JM. *Fundamentos de Diseño y Estadística. Correlación y Regresión lineal*. Barcelona: Signo, 2006:71-76.

Donato AJ, Tench K, Glueck DH, Seals DR, Eskurza I, & Tanaka H. Declines in physiological functional capacity with age: a longitudinal study in peak swimming performance. *J Appl Physiol* 2003;94:764-769.

Drela N, Kozdron E, & Szczypiorski P. Moderate exercise may attenuate some aspects of immunosenescence. *BMC Geriatr* 2004;4:8-15.

Drewnowski AJ, & Evans WJ. Nutrition, physical activity, and quality of live in older adults: summary. *J Gerontol A Biol Sci Med Sci* 2001;56A:M89-M94.

Dubost V, Kressig RW, Gonthier R, Herrmann FR, Aminian K, Najafi B, & Beauchet O. Relationships between dual-task related changes in stride velocity and stride time variability in healthy older adults. *Hum Mov Sci* 2006;25:372-382.

Duncan PW, Chandler J, Studenski S, Hughes M, & Prescott B. How do physiological components of balance affect mobility in elderly men? *Arch Phys Med Rehabil* 1993;74:1343-1349.

Duncan PW, Studenski S, Chandler J, & Prescott B. Functional reach: predictive validity in a sample of elderly male veterans. *J Gerontol* 1992;47:M93-M98.

Duncan PW, Weiner DK, Chandler J, & Studenski S. Functional reach: A new clinical measure of balance. *J Gerontol A Biol Sci Med Sci* 1990;45A:M192-M197.

Eagle J, Salamara S, Whitman D, Evans LA, Ho E, & Olde J. Comparison of Three Instruments in Predicting Accidental Falls in Selected Inpatients in a General Teaching Hospital. *J Gerontol Nurs* 1999;25:40-45.

Eakin EG, Brown WJ, Marshall AL, Mummery K, & Larsen E. Physical activity promotion in primary care: bridging the gap between research and practice. *Am J Prev Med* 2004;27:297-303.

Ekdahl C, Jarnlo GB, & Andersson SI. Standing balance in healthy subjects. *Scand J Rehab Med* 1989;21:187-195.

Ensrud KE, Ewing SK, Taylor BC, Fink HA, Cawthon PM, Stone KL, Hillier TA, Cauley JA, Hochberg MC, Rodondi N, Tracy JK, & Cummings SR. Comparison of 2 frailty indexes for prediction of falls, disability, fractures, and death in older women. *Arch Intern Med* 2008;168:382-389.

Era P, Sainio P, Koskinen S, Haavisto P, Vaara M, & Aromaa A. Postural balance in a random sample of 7,979 subjects aged 30 years and over. *Gerontology* 2006;52:204-213.

Everett MD, Kinser AM, & Ramsey MW. Training for old age: production functions for the aerobic exercise inputs. *Med Sci Sports Exerc* 2007;39:2226-2233.

Exton-Smith AN. Functional consequences of ageing: clinical manifestations. In: Exton-Smith AN, Evans G, editors. *Care of the elderly: meeting the challenge of dependency*. Londres: Academic Press, 1977.

Exton-Smith AN, Smith M, & Weksler E. *Tratado de Geriatria.* Madrid: Jims, 1988:184.

Faber MJ, Bosscher RJ, Chin A Paw MJ, & van Wieringen PC. Effects of exercise programs on falls and mobility in frail and pre-frail older adults: a multicenter randomized controlled trial. *Arch Phys Med Rehabil* 2006;87:885-896.

Fairhall N, Aggar C, Kurrle SE, Sherrington C, Lord S, Lockwood K, Monaghan N, & Cameron ID. Frailty Intervention Trial (FIT). *BMC Geriatr* 2008;8:27.

Fatouros IG, Kambas A, Katrabasas I, Nikolaidis K, Chatzinikolaou A, Leontsini D, & Taxildaris K. Strength training and detraining effects on muscular strength, anaerobic power, and mobility of inactive older men are intensity dependent. *Br J Sports Med* 2005;39:776-780.

Ferrucci L, Guralnik JM, Studenski S, Fried LP, Cutler GB Jr, & Walston JD. Interventions on Frailty Working Group. Designing randomized, controlled trials aimed at preventing or delaying functional decline and disability in frail, older persons: a consensus report. *J Am Geriatr Soc* 2004;52:625-634.

Fiatarone MA, O’Neill EF, Doyle RN, & Clements K. Efficacy of home based resistance training in frail elders (Abstract 985). Abstracts of the 16th Congress of the International Association of Gerontology. Bedford Park, South Australia: World Congress of Gerontology Inc, 1997:323.

Fiatarone MA, O'Neill EF, Ryan ND, Clements KM, Solares GR, Nelson ME, Roberts SB, Kehayias JJ, Lipsitz LA, & Evans WJ. Exercise Training and Nutritional Supplementation for Physical Frailty in Very Elderly People. *N Engl J Med* 1994;330:1769-1775.

Fierro A. Proposiciones y propuestas sobre el buen envejecer. In: Buendía J, editor. *Envejecimiento y psicología de la salud.* Madrid: Siglo XXI de España, 1994:3-33.

Finch CE, & Kirkwood TBL. *Chance, Development and Aging*. Oxford: Oxford University Press, 2000.

Fitzpatrick R, Rogers DK, & McClosky DI. Stable human standing with lower-limb muscle afferents providing the only sensory input. *J Physiol* 1994;480:395-403.

Foldvari M, Clark M, Laviolette LC, Bernstein MA, Kaliton D, Castaneda C, Pu CT, Hausdorff JM, Fielding RA, & Singh MA. Association of muscle power with functional status in community-dwelling elderly women. *J Gerontol A Biol Sci Med Sci* 2000;55A:M192-M199.

Forssberg H, Grillner S, & Halbertsma J. The locomotion of the low spinal cat. I. Coordination within a hindlimb. *Acta Physiol Scand* 1980;108:269-281.

Fozard JL, Vercryssen M, Reynolds SL, Hancock PA, & Quilter RE. Age differences and changes in reaction time: the Baltimore Longitudinal Study of Aging. *J Gerontol* 1994;49:179-189.

Freedman VA, Hodgson N, Lynn J, Spillman BC, Waidmann T, Wilkinson AM, & Wolf DA. Promoting Declines in the Prevalence of Late-Life Disability: Comparisons of Three Potentially High-Impact Interventions. *Milbank Q* 2006;84:493-520.

Fried LP, Bandeen-Roche K, Chaves PH, & Johnson BA. Preclinical mobility disability predicts incident mobility disability in older women. *J Gerontol A Biol Sci Med Sci* 2000;55A:M43-M52.

Fried LP, Ferrucci L, Darer J, Williamson JD, & Anderson G. Untangling the concepts of disability, frailty, and co morbidity: implications for improved targeting and care. *J Gerontol A Biol Sci Med Sci* 2004;59A:M255-M263.

Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, Seeman T, Tracy R, Kop WJ, Burke G, McBurnie MA; & Cardiovascular Health Study Collaborative Research Group. Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci* 2001;56A:M146-M156.

Fries JF. *Aging well*. Merlo Park (California): Adison Wesley, 1990.

Fries JF, & Crapo LM. *Vitality and aging.* San Francisco: W. H. Freeman, 1981.

Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ, & Roubenoff R. Aging of skeletal muscle: a 12-yr longitudinal study. *J Appl Physiol* 2000;88:1321-1326.

Gabriel DA, Kamen G, & Frost G. Neural adaptations to resistive exercise: mechanisms and recommendations for training practices. *Sports Med* 2006;36:133-149.

Gagey PM, & Weber B. Prefacio. In: Gagey PM, Weber B, editors. *Posturología. Regulación y alteraciones de la bipedestación.* Barcelona: Masson, 2001.

Gardner MM, Robertson MG, & Campbell AJ. Exercise in preventing falls and fall related injuries in older people: A review of randomized controlled trials. *Brit J Sports Med* 2000;34:7-17.

Gibson MJ, Andres RO, Isaacs B, Radebaugh T, & Worm-Petersen J. The prevention of falls in later life. A report of the Kellog International Work Group on the prevention of falls by the elderly. *Dan Med Bull* 1987;34:1-24.

Gill TM, Baker DI, Gottschalk M, Peduzzi PN, Allore H, & Byers A. A program to prevent functional decline in physically frail, elderly persons who live at home. *N Engl J Med* 2002;347:1068-1074.

Gill TM, Gahbauer EA, Allore HG, & Han L. Transitions between Frailty States among community-living older persons. *Arch Intern Med* 2006;166:418-423.

Gillespie LD, Gillespie WJ, Robertson MC, Lamb SE, Cumming RG, & Rowe BH. Interventions for preventing falls in elderly people. *Cochrane Database of Systematic Reviews* 2003, Issue 2. Art. No.: CD000340. Available at: http//members.aol.com/tgolberg/prevrecs. Accessed February, 2005.

Giné-Garriga M, Guerra M, Manini TM, Marí-Dell'Olmo M, Pagès E, & Unnithan VB. Measuring Balance, Lower Extremity Strength and Gait in the Elderly: Construct Validation of an Instrument. *Arch Gerontol Geriatr* [In press].

Giné-Garriga M, Guerra M, Marí-Dell'Olmo M, Martin C, & Unnithan VB. Sensitivity of a modified version of the 'Timed Get Up and Go' Test to predict fall risk in the elderly: a pilot study. *Arch Gerontol Geriatr* 2009;49:e60-66.

Giné-Garriga M, Guerra M, Pagès E, Manini TM, Jiménez R, & Unnithan VB. The effect of functional circuit training on physical frailty in frail older adults: a randomized controlled trial. *J Aging Phys Act* [In press].

Goodpaster BH, Carlson CL, Visser M, Kelley DE, Scherzinger A, Harris TB, Stamm E, & Newman AB. Attenuation of skeletal muscle and strength in the elderly: The Health ABC Study. *J Appl Physiol* 2001;90:2157-2165.

Goodpaster BH, Park SW, Harris TB, Kritchevsky SB, Nevitt M, Schwartz AV, Simonsick EM, Tylavsky FA, Visser M, & Newman AB. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci* 2006;61A:M1059-M1064.

Grabiner MD, & Enoka RM. Changes in movement capabilities with aging. *Exerc Sport Sci Rev* 1995;23:65-104.

Grabiner MD, & Jahnigen DW. Modeling recovery from stumbles: preliminary data on variable selection and classification efficacy. *J Am Geriatr Soc* 1992;40:910-913.

Grimley J, & Franklin T. *Oxford textbook of Geriatric Medicine.* New York: Oxford University Press, 1992.

Guralnik JM, Alecxih L, Branch LG, & Wiener JM. Medical and long-term care costs when older persons become more dependent. *Am J Public Health* 2002;92:1244-1245.

Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, & Wallace RB. Lower-extremity function in persons over the age of 70 years as predictor of subsequent disability. *N Engl J Med* 1995;332:556-561.

Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, Scherr PA, & Wallace RB. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediciton of mortality and nursing home admission. *J Gerontol A Biol Sci Med Sci* 1994;49A:M85-M94.

Guyton AC, & Hall JE. *Tratado de Fisiología Médica*. Madrid: Elsevier, 2007.

Habak C, Wilkinson F, & Wilson HR. Aging disrupts the neural transformations that link facial identity across views. *Vision Res* 2008;48:9-15.

Hagemon PA. Age and gender effects on postural control measues. *Arch Phys Med Rehabil* 1995;76:961-965.

Hakkinen K, Kraemer WJ, Newton RU, & Alen M. Changes in electromyographic activity, muscle fibre and force production characteristics during heavy resistance/power strength training in middle-aged and older men and women. *Acta Physiol Scand* 2001;171:51-62.

Halar EM, Hammond MC, LaCava EC, Camann C, & Ward J. Sensory perception threshold measurement: an evaluation of semiobjective testing devices. *Arch Phys Med Rehabil* 1987;68:499-507.

Ham RJ, & Sloane PD. *Atención Primaria en Geriatria. Casos Clínicos.* Madrid: Mosby/ Doyma Libros, 1995.

Handler P. Radiation and Aging. In: Shock NW, editor. *Aging*. Washington: American Association for the Advancement of Sciences, 1960.

Harada N, Chiu V, Damron-Rodriguez J, Fowler E, Siu A, & Reuben DB. Screening for balance and mobility impairment in elderly individuals living in residential care facilities. *Phys Ther* 1995;75:462-469.

Harridge SDR, Kryger A, & Stensgaard A. Knee extensor strength, activation, and size in very elderly people following strength training. *Muscle Nerve* 1999;22:831-839.

Hayflick L. The Future of aging. *Nature* 2000;408:267-269.

Heitmann DK, Gossman MR, Shaddeau SA, & Jackson JR. Balance performance and step width in noninstitutionalized elderly female fallers and nonfallers. *Phys Ther* 1989;69:923-931.

Hertzman C, Power C, Matthews S, & Manor O. Using an interactive framework of society and lifecourse to explain self-rated health in early adulthood. *Soc Sci Med* 2001;53:1575–85.

Hogan DB, MacDonald FA, & Betts J. A randomized controlled trial of a community-based consultation service to prevent falls. *CMAJ* 2001;165:537-543.

Horak FB, & McPherson JM. Postural orientation and equilibrium. In: Sephard J, Rowell L, editors. *Handbook of physiology. Exercise: regulation and integration of multiple systems.* New York: Oxford University Press, 1996.

Hortobágyi T, Tunnel D, Moody J, Beam S, & DeVita P. Low- or highintensity strength training partially restores impaired quadriceps force accuracy and steadiness in aged adults. *J Gerontol A Biol Sci Med Sci* 2001;56A:B38-B47.

Howe TE, Rochester L, Jackson A, Banks PMH, & Blair VA. Exercise for improving balance in older people. *Cochrane Database of Systematic Reviews* 2007, Issue 4. Art. No.: CD004963. DOI: 10.1002/14651858.CD004963.pub2.

Howley C, & Franks A. *Manual del técnico en salud y fitness.* Barcelona: Paidotribo, 1995.

Hruda KV, Hicks AL, & McCartney N. Training for muscle power in older adults: effects on functional abilities. *Can J Appl Physiol* 2003;28:178-189.

Hubbard RE, Fallah N, Searle SD, Mitnitski A, & Rockwood K. Impact of exercise in community-dwelling older adults. *PLoS One* 2009;4:e6174.

Hughes VA, Frontera WR, Wood M, Evans WJ, Dallal GE, Roubenoff R, & Fiatarone Singh MA. Longitudinal muscle strength changes in older adults: influence of muscle mass, physical activity, and health. *J Gerontol A Biol Sci Med Sci* 2001;56A:B209-B217.

Iezzoni LI, McCarthy EP, Davis RB, & Siebens H. Mobility problems and perceptions of disability by self-respondents and proxy respondents. *Med Care* 2000;38:1051-1057.

Islam MM, Nasu E, Rogers ME, Koizumi D, Rogers NL, & Takeshima N. Effects of combined sensory and muscular training on balance in Japanese older adults. *Prev Med* 2004;39:1148-1155.

Ivers RQ, Cumming RG, Mitchell P, & Attebo K. Visual impairment and falls in older adults: the Blue Mountains eye study. *J Am Geriatr Soc* 1998;46:58-64.

Iverson BD, Gossman MR, Shaddeau SA, & Turner ME Jr. Balance performance, force production, and activity levels in noninstitutionalized men 60 to 90 years of age. *Phys Ther* 1990;70:348-355.

Janssen I, Heymsfield SB, Wang ZM, & Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. *J Appl Physiol* 2000;89:81-88.

Jessup JV, Horne C, Vishen RK, & Wheeler D. Effects of exercise on bone density, balance, and self-efficacy in older women. *Biol Res Nurs* 2003;4:171-180.

Jiménez F, & Aguilar A. *Isocinéticos: Metodología y utilización*. Madrid: Mapfre, 2000.

Jones CJ, & Rose DJ. Physical Activity Instruction of Older Adults. Champaign, IL: Human Kinetics Publishers, 2005.

Judge JO, Davis RB 3rd, & Ounpuu S. Step length reductions in advanced age: the role of ankle and hip kinetics. *J Gerontol A Biol Sci Med Sci* 1996;51A:M303-M312.

Judge JO, Lindsey C, Underwood M, & Winsemius D. Balance improvements in older women: effects of exercise training. *Phys Ther* 1993;73:254-265.

Kannus P, Sievanen H, Palvanen M, Jarvinen T, & Parkkari J. Prevention of falls and consequent injuries in elderly people. *Lancet* 2005;366:1885-1893.

Karamanidis K, & Arampatzis A. Mechanical and morphological properties of different muscle-tendon units in the lower extremity and running mechanics: effect of aging and physical activity. *J Exp Biol* 2005;208:3907-3923.

Katsiaras A, Newman AB, Kriska A, Brach J, Krishnaswami S, Feingold E, Kritchevsky SB, Li R, Harris TB, Schwartz A, & Goodpaster BH. Skeletal muscle fatigue, strength, and quality in the elderly: the Health ABC Study. *J Appl Physiol* 2005;99:210-216.

Katz S, Branch LG, Branson MH, Papsidero JA, Beck JC, & Greer DS. Active life expectancy. *N Engl J Med* 1983;309:1218-1224.

Kellis E, & Baltzopoulos V. Resistive eccentric exercise: effects of visual feedback on maximum moment of knee extensors and flexors. *J Orthop Sports Phys Ther* 1996;23:120-124.

Kenshalo DR. Somesthetic sensitivity in young and elderly humans. *J Gerontol* 1986;41:732-742.

Khasnis A, & Gokula RM. Romberg's test. *J Postgrad Med* 2003;49:169-172.

Kinsella K, & Velkoff VA. *Aging World: 2001. International Population Reports*. Washington: Census Bureau, 2001.

Klein BE, Klein R, Lee KE, & Cruickshanks KJ. Performance-based and self-assessed measures of visual function as related to history of falls, hip fractures, and measured gait time. The Beaver Dam Eye Study. *Ophthalmology* 1998;105:160-164.

Kriska AM, & Caspersen CJ. Introduction to a collection of Physical Activity Questionnaires. *Med Sci Sports Exerc* 1997;29:5-9.

Krivickas LS, Suh D, Wilkins J, Hughes VA, Roubenoff R, & Frontera WR. Age- and gender-related differences in maximum shortening velocity of skeletal muscle fibres. *Am J Phys Med Rehabil* 2001;80:447-455.

Kuh D, & Davey Smith G. When is mortality risk determined? Historical insights into a current debate. *Soc Hist Med* 1993;6:101-123.

Landi F, Onder G, Carpenter I, Cesari M, Soldato M, & Bernabei R. Physical activity prevented functional decline among frail community-living elderly subjects in an international observational study. *J Clin Epidemiol* 2007;60:518-524.

Lanska DJ. The Romberg sign and early instruments for measuring postural sway. *Semin Neurol* 2002;22:409-418.

Latham NK, Anderson CS, Lee A, Bennett DA, Moseley A, & Cameron ID. A randomized, controlled trial of quadriceps resistance exercise and vitamin D in frail older people: The Frailty Interventions Trial in Elderly Subjects (FITNESS). *J Am Geriatr Soc* 2003;51:291-299.

Lázaro M, Cuesta F, León A, Sánchez C, Feijoo R, Montiel M, & Ribera JM. Valor de la posturografía en ancianos con caídas de repetición. *Med Clin* 2005;124:207-210.

Lee LW, & Kerrigan DC. Identification of kinetic differences between fallers and nonfallers in the elderly. *Am J Phys Med Rehabil* 1999;78:242-246.

Lemmer JT, Hurlbut DE, Martel GF, Tracy BL, Ivey FM, Metter EJ, Fozard JL, Fleg JL, & Hurley BF. Age and gender responses to strength training and detraining. *Med Sci Sports Exerc* 2000;32:1505-1512.

Lexell J, Downham DY, Larsson Y, Bruhn E, & Morsing B. Heavy resistance training in older Scandinavian men and women: short- and long-term effects on arm and leg muscles. *Scand J Med Sci Sports* 1995;5:329-341.

Lexell J, Taylor CC, & Sjostrom M. What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *J Neurol Sci* 1988;84:275-294.

Lichtenstein MJ, Shields SL, Shiavi RG, & Burger MC. Exercise and balance in aged women: a pilot controlled clinical trial. *Arch Phys Med Rehabil* 1989;70:138-143.

Lindenberger U, Marsiske M, & Baltes PB. Memorizing while walking: increase in dual-task costs from young adulthood to old age. *Psychol Aging* 2000;15:417-436.

Littbrand H, Lundin-Olsson L, Gustafson Y, & Rosendahl E. The Effect of a High-Intensity Functional Exercise Program on Activities of Daily Living: A Randomized Controlled Trial in Residential Care Facilities. *J Am Geriatr Soc* 2009;57:1741-1749.

Lopopolo RB, Greco M, Sullivan D, Craik RL, & Mangione KK. Effect of therapeutic exercise on gait speed in community-dwelling elderly people: a meta-analysis. *Phys Ther* 2006;86:520-540.

Lord SR, Castell S, Corcoran J, Dayhew J, Matters B, Shan A, & Williams P. The effect of group exercise on physical functioning and falls in frail older people living in retirement villages: a randomized controlled trial. *J Am Geriatr Soc* 2003;51:1685-1692.

Lord SR, Clark RD, & Webster IW. Physiological factors associated with falls in an elderly population. *J Am Geriatr Soc* 1991;39:1194-1200.

Lord SR, & Dayhew J. Visual risk factors for falls in older people. *J Am Geriatr Soc* 2001;49:508-515.

Lord SR, & Fitzpatrick RD. Choice stepping reaction time: a composite measure of falls risk in older people. *J Gerontol A Biol Sci Med Sci* 2001;56A:M627-M632.

Lord SR, Lloyd DG, & Li SK. Sensori-motor function, gait patterns and falls in community-dweeling women. *Age ageing* 1996;25:292-299.

Lord SR, Murray SM, Chapman K, Munro B, & Tiedemann A. Sit-to-stand depends on sensation, speed, balance, and psychological status in addition to strength in older people. *J Gerontol A Biol Sci Med Sci* 2002;57A:M539-M543.

Lord SR, Rogers MW, Howland A, & Fitzpatrick R. Lateral stability, sensorimotor function and falls in older people. *J Am Geriatr Soc* 1999;47:1077-1081.

Lord SR, Sherrington C, & Menz H. *Falls in older people: Risk factors and strategies for prevention*. Cambridge: Cambridge University Press, 2001.

Lord SR, Tiedemann A, Chapman K, Munro B, Murray SM, & Sherrington C. The effect of an individualized fall prevention program on fall risk and falls in older people: a randomized, controlled trial. *J Am Geriatr Soc* 2005;53:1296-1304.

Lord SR, Ward JA, Williams P, & Anstey KJ. An epidemiological study of falls in older community-dwelling women: the Randwick falls and fractures study. *Aust J Public Health* 1993;17:240-245.

Lord SR, Ward JA, Williams P, & Anstey KJ. Physiological factors associated with falls in older community-dwelling women. *J Am Geriatr Soc* 1994;42:1110-1117.

Lord SR, Ward JA, Williams P, & Strudwick M. The effect of a 12-month exercise trial on balance, strength, and falls in older women: a randomized controlled trial. *J Am Geriatr Soc* 1995;43:1198-1206.

Luchies CW, Alexander NB, Schultz AB, & Ashton-Miller JA. Stepping responses of young and old adults to postural disturbances: kinematics. *J Am Geriatr Soc* 1994;42:506-512.

Luukinen H, Koski K, Hiltunen L, & Kivelä SL. Incidence rate of falls in an aged population in northern Finland. *J Clin Epidemiol* 1994;47:843-850.

Mahoney FI, & Barthel DW. Functional evaluation: The Barthel Index. A simple index of independence useful in scoring improvement in the rehabilitation of the chronically ill. *Md State Med J* 1965;14:61-65.

Maki BE, Holliday PJ, & Fernie GR. Aging and postural control: a comparison of spontaneous- and induced- sway balance tests. *J Am Geriatr Soc* 1990;38:1-9.

Maki BE, Holliday PJ, & Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *J Gerontol* 1994;49:M72-M84.

Manini T, Marko M, VanArnam T, Cook S, Fernhall B, Burke J, & Ploutz-Snyder L. Efficacy of resistance and task-specific exercise in older adults who modify tasks of everyday life. *J Gerontol A Biol Sci Med Sci* 2007;62A:M616-M623.

Mann RA, Mann JA. Biomechanics of the foot. In: Goldberg B, Hsu JD, editors. *Atlas of orthoses and assistive devices*. St. Louis: Mosby, 1997:135-152.

Manso J, Valdivieso M, & Caballero J. *Pruebas para la Valoración de la Capacidad Motriz en Deporte.* Madrid: Gymons Editorial Deportiva, 1996.

Masuda K, Kikuhara N, Demura S, Katsuta S, & Yamanaka K. Relationship between muscle strength in various isokinetic movements and kick performance among soccer players. *J Sports Med Phys Fitness* 2005;45:44-52.

Mathias S, Nayak U, & Isaacs B. Balance in elderly patients: the “Get Up and Go” test. *Arch Phys Med Rehabil* 1986;67:387-389.

McAuley E, Kramer AF, & Colcombe SJ. Cardiovascular fitness and neurocognitive function in older adults: a brief review. *Brain Behav Immun* 2004;18:214-220.

Medell J, & Alexander NB. A clinical measure of maximal and rapid stepping in older women. *J Gerontol A Biol Sci Med Sci* 2000;55A:M429-M433.

Melis RJ, van Eijken MI, Teerenstra S, van Achterberg T, Parker SG, Borm GF, van de Lisdonk EH, Wensing M, & Rikkert MG. A randomized study of a multidisciplinary program to intervene on geriatric syndromes in vulnerable older people who live at home (Dutch EASYcare Study). *J Gerontol A Biol Sci Med Sci* 2008;63A:M283-M290.

Melzer I, Benjuya N, & Kaplanski J. Postural stability in the elderly: a comparison between fallers and non-fallers. *Age ageing* 2004;33:602-607.

Menéndez-Colino R, Sánchez C, De Tena A, Lázaro M, Cuesta F, & Ribera JM. Utilidad de la estación unipodal en la valoración del riesgo de caídas. *Rev Esp Geriatr Gerontol* 2005;40:18-23.

Metter EJ, Lynch N, Conwit R, Lindle R, Tobin J, & Hurley B. Muscle quality and age: cross-sectional and longitudinal comparisons. *J Gerontol A Biol Sci Med Sci* 1999;54A:B207-B218.

Miller MD, Crotty M, Whitehead C, Bannerman E, & Daniels LA. Nutritional supplementation and resistance training in nutritionally at risk older adults following lower limb fracture: a randomised controlled trial. *Clin Rehab* 2006;20:311-323.

Moher D, Schulz KF, & Altman DG. The CONSORT statement. Revised recommendations for improving the quality of reports of parallel-group randomised trials. *Lancet* 2001;357:1191–1194.

Montero-Odasso M, Schapira M, Soriano ER, Varela M, Kaplan R, Camera LA, & Mayorga LM. Gait velocity as a single predictor of adverse events in healthy seniors aged 75 years and older. *J Gerontol A Biol Sci Med Sci* 2005;60A:M1304-M1309.

Morley JE, Baumgartner RN, Roubenoff R, Mayer J, & Nair KS. Sarcopenia. *J Lab Clin Med* 2001;137:231-243.

Morris R. Predicting falls in older women. *Menopause Int* 2007;13:170-177.

Muir SW, Berg K, Chesworth B, & Speechley M. Use of the Berg Balance Scale for Predicting Multiple Falls in Community-Dwelling Elderly People: A Prospective Study. *Phys Ther* 2008;88:449-459.

Narici MV, Maganaris CN, Reeves ND, & Capodaglio P. Effect of aging on human muscle architecture. *J Appl Physiol* 2003;95:2229-2234.

Nashner LM, & Peters JF. Dynamic posturography in the diagnosis and management of dizziness and balance disorders. *Neurol Clin* 1990;8:331-349.

Nelson ME, Layne JE, Bernstein MJ, Nuernberger A, Castaneda C, Kaliton D, Hausdorff J, Judge JO, Buchner DM, Roubenoff R, & Fiatarone Singh MA. The effects of multidimensional home-based exercise on functional performance in elderly people. *J Gerontol A Biol Sci Med Sci* 2004;59A:M154-M160.

Nevitt MC, Cummings SR, Kidd S, & Black D. Risks factors for recurrent nonsyncopal falls: a prospective study. *J Am Med Assoc* 1989;261:2663-2668.

Newman AB, Kupelian V, Visser M, Simonsick EM, Goodpaster BH, Kritchevsky SB, Tylavsky FA, Rubin SM, & Harris TB. Strength, but not muscle mass, is associated with mortality in the Health, Aging and Body Composition Study cohort. *J Gerontol A Biol Sci Med Sci* 2006;61A:M72-M77.

Nguyen T, Sambrook P, Kelly P, Jones G, Lord S, Freund J, & Eisman J. Prediction of osteoporotic fractures by postural stability and bone density. *BMJ* 1993;307:1111-1115.

Norman A, Bellocco R, Bergström A, & Wolk A. Validity and reproducibility of self-reported total physical activity-differences by relative weight. *Int J Obes* 2001;25:682-688.

Nowalk MP, Prendergast JM, Bayles CM, D'Amico FJ, & Colvin GC. A randomized trial of exercise programs among older individuals living in two long-term care facilities: The fallsfree program. *J Am Geriatr Soc* 2001;49: 859-865.

Okumiya K, Matsubayashi K, Nakamura T, Fujisawa M, Osaki Y, Doi Y, & Ozawa T. The Timed "Up & Go" test is a useful predictor of falls in community-dwelling older people. *J Am Geriatr Soc* 1998;46:928-930.

Oliver D, Hopper A, & Seed P. Do hospital fall prevention programmes work? A systematic review. *J Am Geriatr Soc* 2000;38:1679-1689.

Ollonqvist K, Grönlund R, Karppi SL, Salmelainen U, Poikkeus L, & Hinkka K. A network-based rehabilitation model for frail elderly people: development and assessment of a new model. *Scand J Caring Sci* 2007;21:253-261.

Ortega MA, Roca G, Iglesias M, & Jurado JM. Patients over-using a primary care centre: their social, demographic and clinical characteristics, and their use of health service facilities. *Aten Primaria* 2004;33:78-85.

Ortuño MA, Viosca E, & Baydal JM. Validación del sistema de valoración del equilibrio NedSVE-IBV. Valencia, Spain: III Jornadas de usuarios de Valoración Funcional del Instituto de Biomecánica de Valencia, 2007.

Ory MG, Schechtman KB, Miller P, Hadley EC, Fiatarone MA, Province MA, Arfken CL, Morgan D, Weiss S, & Kaplan M. Frailty and injuries in later life: the FICSIT Trials. *J Am Geriatr Soc* 1993;41:283-296.

Patten CT, Kamen G, & Rowland DM. Adaptations in maximal motor unit discharge rate to strength training in young and older adults. *Muscle Nerve* 2001;24:542-550.

Pavol MJ, Owings TM, Foley KT, & Grabiner MD. Influence of lower extremity strength of healthy older adults on the outcome of an induced trip. *J Am Geriatr Soc* 2002;50:256-262.

Pereira MA, Kriska AM, Day RD, Cauley JA, LaPorte RE, & Kuller LH. A randomized walking trial in postmenopausal women: effects on physical activity and health 10 years later. *Arch Intern Med* 1998;158:1695-1701.

Perell KL, Nelson A, Goldman RL, Luther SL, Prieto-Lewis N, & Rubenstein LZ. Fall risk assessment measures: an analytic review. *J Gerontol A Biol Sci Med Sci* 2001;56A: M761-M766.

Perrin DH. *Isokinetic exercise and assessment.* Charlottesville: Human Kinetics, 1993.

Peterson MJ, Giuliani C, Morey MC, Pieper CF, Evenson KR, Mercer V, Cohen HJ, Visser M, Brach JS, Kritchevsky SB, Goodpaster BH, Rubin S, Satterfield S, Newman AB, Simonsick EM; Health, & Aging and Body Composition Study Research Group. Physical activity as a preventative factor for frailty: the health, aging, and body composition study. *J Gerontol A Biol Sci Med Sci* 2009;64A:M61-M68.

Piirtola M, & Era P. Force platform measurements as predictors of falls among older people - a review. *Gerontology* 2006;52:1-16.

Ploutz-Snyder LL, Manini T, Ploutz-Snyder RJ, & Wolf DA. Functionally relevant thresholds of quadriceps femoris strength. *J Gerontol A Biol Sci Med Sci* 2002;57A:B144-B152.

Podsiadlo D, & Richardson S. The Timed “Up and Go”: A test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc* 1991;39:142-148.

Pols MA, Peeters PH, Kemper HC, & Collette HJ. Repeatability and Relative Validity of Two Physical Activity Questionnaires in elderly women. *Med Sci Sports Exerc* 1996;28:1020-1025.

Powell LE, & Myers AM. The activities-specific balance confidence (ABC) scale. *J Gerontol A Biol Sci Med Sci* 1995;50A:M28-M34.

Raîche M, Hébert R, Prince F, & Corriveau H. Screening older adults at risk of falling with the Tinetti balance scale. Lancet 2000;356:1001-1002.

Rantanen T. Muscle strength, disability and mortality. *Scand J Med Sci Sports* 2003;13:3-8.

Rantanen T, Avlund K, Suominen H, Schroll M, Frandin K, & Pertti E. Muscle strength as a predictor of onset of ADL dependence in people aged 75 years. *Aging Clin Exp Res* 2002;14:10-15.

Reig-Ferrer A. Psicología de la vejez. Comportamiento y adaptación. In: Fernández-Ballesteros R, editor. *Gerontología social.* Madrid: Pirámide, 2000:167-195.

Reuben DB, Herr K, Pacala JP, & Potter JF. *Geriatrics at your fingertips.* New York: Medical Trends, American Geriatrics Society, 2002.

Ribera-Casado JM, & Cruz-Jentoft AJ. *Geriatría. Formación Continuada en Atención Primaria.* Madrid: Idepsa, 1991:75-81.

Richardson JK, Ching C, & Hurvitz EA. The relationship between electromyographically documented peripheral neuropathy and falls. *J Am Geriatr Soc* 1992;40:1008-1012.

Rikli R, & Jones CJ. Functional fitness normative scores for community-residing older adults, ages 60-94. *J Aging Phys Act* 1999;7:162-181.

Robbins AS, Rubenstein LZ, Josephson KR, Schulman BL, Osterweil D, & Fine G. Predictors of falls among elderly people. Results of two population-based studies. *Arch Intern Med* 1989;149:1628-1633.

Robertson MC, Devlin N, Gardner MM, & Campbell AJ. Effectiveness and economic evaluation of a nurse delivered home exercise programme to prevent falls. 1: Randomised controlled trial. *BMJ* 2001;322:697-701.

Rockwood K. What would make a definition of frailty successful? *Age Ageing* 2005;34:432-434.

Rockwood K, Song X, MacKnight C, Bergman H, Hogan DB, McDowell I, & Mitnitski A. A global clinical measure of fitness and frailty in elderly people. *CMAJ* 2005;173:489-495.

Rockwood K, Stadnyk K, MacKnight C, McDowell I, Hébert R, & Hogan DB. A brief clinical instrument to classify frailty in elderly people. *Lancet* 1999;353:205-206.

Rodríguez A. Dimensiones psicosociales de la vejez. In: Buendía J, editor. *Envejecimiento y psicología de la salud.* Madrid: Siglo XXI de España, 1994:53-67.

Rogers MA, & Evans WJ. Changes in skeletal muscle with aging: effects of exercise training. *Exerc Sports Sci Rev* 1993;21:65-102.

Rose DJ. *Fallproof. A comprehensive balance and mobility program.* Champaign, Ill: Human Kinetics, 2003.

Rose DJ, Jones CJ, & Lucchese N. Predicting the probability of falls in community-residing older adults using the 8-foot up-and-go: a new measure of functional mobility. *J Phys Activity Aging* 2002;10:466-475.

Rosendahl E, Lindelöf N, Littbrand H, Yifter-Lindgren E, Lundin-Olsson L, Håglin L, Gustafson Y, & Nyberg L. High-intensity functional exercise program and protein-enriched energy supplement for older persons dependent in activities of daily living: a randomised controlled trial. *Aust J Physiother* 2006;52:105-113.

Rothman ED, & Ericson WA. *Statistics: Methods and Applications.* Iowa: Kendall/Hunt Publishing Co, 1987:203.

Roudaia E, Bennett PJ, & Sekuler AB. The effect of aging on contour integration. *Vision Res* 2008;48:2767-2774.

Rousselet GA, Husk JS, Pernet CR, Gaspar CM, Bennett PJ, & Sekuler AB. Age-related delay in information accrual for faces: evidence from a parametric, single-trial EEG approach. *BMC Neurosci* 2009;10:114.

Rowe JW, & Kahn RL. Successful aging. *Gerontologist* 1997;37:433-440.

Royal College of Nursing. *Clinical practice guideline for the assessment and prevention of falls in older people.* Guideline commissioned by the National Institute for Clinical Excellence. Londres: Royal College of Nursing, 2004.

Rubenstein LZ, Josephson KR, Trueblood PR, Loy S, Harker JO, Pietruszka FM, & Robbins AS. Effects of a group exercise program on strength, mobility, and falls among fall-prone elderly men. *J Gerontol A Biol Sci Med Sci* 2000;55A:M317-M321.

Rutter M. Pathways from childhood to adult life. *J Child Psychol Psychiatry* 1989;30:25-51.

Rydwik E, Frandin K, & Akner G. Effects of physical training on physical performance in institutionalised elderly patients (70+) with multiple diagnoses. *Age Ageing* 2004;33:13-23.

Salleras Ll, Taberner JL, Tresserres R, Salvà A, Morera R, Martín Zurro A, Cervera AM, Ribot J, & Ballesteros E. Actividades preventivas escalonadas en las personas mayores. *Med Clin (Barc)* 2001;116(Supl 1):153-157.

Salvà A, Bolívar I, Lucas R, & Rojano-Luque X. Utilización del POMA en nuestro medio para la valoración del equilibrio y la marcha en una población de personas mayores residentes en la comunidad. *Rev Esp Geriatr Gerontol* 2005;40:36-44.

Schieber F. Vision and Aging. In: Birren JE & Schaie KW, editors. *Handbook of the Psychology of Aging.* London: Academic Press, 2006:129-161.

Schmid A, Duncan P, Studenski S, Lai S, Richards L, Perera S, & Wu S. Improvements in speed-based gait classifications are meaningful. *Stroke* 2007;38:2096-2100.

Schnelle JF, Alessi CA, Simmons SF, Al-Samarrai NR, Beck JC, & Ouslander JG. Translating clinical research into practice: a randomized controlled trial of exercise and incontinence care with nursing home residents. *J Am Geriatr Soc* 2002;50:1476-1483.

Seidler RD, Alberts JL, & Stelmach GE. Changes in multi-joint performance with age. *Motor Control* 2002;6:19-31.

Seynnes O, Fiatarone Singh MA, Hue O, Pras P, Legros P, & Bernard PL. Physiological and functional responses to low-moderate versus high-intensity progressive resistance training in frail elders. *J Gerontol A Biol Sci Med Sci* 2004;59A:M503-M509.

Shah S, Vanclay F, & Cooper B. Improving the sensitivity of the Barthel Index for stroke rehabilitation. *J Clin Epidemiol* 1989;42:703-709.

Sheldon JH. The effect of age on the control of sway. *Gerontologia Clinica* 1963;5:129-138.

Shimada H, Obuchi S, Furuna T, & Suzuki T. New intervention program for preventing falls among frail elderly people: the effects of perturbed walking exercise using a bilateral separated treadmill. *Am J Phys Med Rehabil* 2004;83:493-499.

Shimada H, Obuchi S, Kamide N, Shiba Y, Okamoto M, & Kakurai S. Relationship with dynamic balance function during standing and walking. *Am J Phys Med Rehabil* 2003;82:511-516.

Shumway-Cook A, Brauer S, & Woollacott M. Predicting the probability for falls in community-dwelling older adults using the timed up and go test. *Phys Ther* 2000;80:896-903.

Shumway-Cook A, Guralnik JM, Phillips CL, Coppin AK, Ciol MA, Bandinelli S, & Ferrucci L. Age-associated declines in complex walking task performance: the Walking InCHIANTI Toolkit. *J Am Geriatr Soc* 2007;55:58-65.

Shumway-Cook A, & Horak FB. Assessing the influence of sensory interaction of balance. Suggestion from the field. *Phys Ther* 1986;66:1548-1550.

Shumway-Cook A, & Woollacott M. *Motor Control: Theory and Practical Applications.* Baltimore: Williams & Wilkins, 1995:322-324.

Simpson JM, Worsfold C, Reilly E, & Nye N. A standard procedure for using Turn 180º: testing dynamic postural stability among elderly people. *Physiotherapy* 2002;88:342-353.

Sintes E, & Ramón A. *Condicions de vida i hàbits de la gent gran de la província de Barcelona*. Barcelona: Diputació de Barcelona, 2003.

Skelton DA, Greig CA, Davies JM, & Young A. Strength and power related functional ability of healthy people aged 65-89 years. *Age ageing* 1994;23:371-377.

Skelton DA, Kennedy J, & Rutherford OM. Lower limb muscle strength and power in community dwelling female fallers and non-fallers aged over 65. *J Physiol* 2001;531-548.

Skelton DA, & McLaughlin AW. Training Functional Ability in Old Age. *Physiotherapy* 1996;82:159-167.

Skelton DA, Young A, Greig CA, & Malbut KE. Effects of resistance training on strength, power, and selected functional abilities of women aged 75 and older. *J Am Geriatr Soc* 1995;43:1081-1087.

Soler À. *Evaluación de la eficacia del programa de intervención psico-socio-motriz para ancianos (PIPSMA) sobre el bienestar de las personas mayores*. Tesis Doctoral. Barcelona: Universitat de Barcelona, 2003.

Speechley M, & Tinetti M. Falls and injuries in frail and vigorous community elderly persons. *J Am Geriatr Soc* 1991;395:46-52.

Spirduso WW. *Pysical dimensions of aging*. Champaign (Illinois): Human Kinetics, 1995.

Steinberg M, Cartwright C, Peel N, & Williams G. A sustainable programme to prevent falls and near falls in community dwelling older people: results of a randomised trial. *J Epidemiol Community Health* 2000;54:227-232.

Stelmach GE, & Worringham CJ. Sensorimotor deficits related to postural stability. Implications for falling in the elderly. *Clin Geriatr Med* 1985;1:679-694.

Studenski S, Hayes RP, Leibowitz RQ, Bode R, Lavery L, Walston J, Duncan P, & Perera S. Clinical global impression of change in physical frailty: development of a measure based on clinical judgement. *J Am Geriatr Soc* 2004;52:1560-1566.

Studenski S, Perera S, Wallace D, Chandler JM, Duncan PW, Rooney E, Fox M, & Guralnik JM. Physical performance measures in the clinical setting. *J Am Geriatr Soc* 2003;51:314-322.

Sturnieks DL, St George R, & Lord SR. Balance disorders in the elderly. *Neurophysiol Clin* 2008;38:467-478.

Sudarsky L. Geriatrics: gait disorders in the elderly. *N Engl J Med* 1990;322:1441-1446.

Suetta C, Aagaard P, Rosted A, Jakobsen AK, Duus B, Kjaer M, & Magnusson SP. Training-induced changes in muscle CSA, muscle strength, EMG, and rate of force development in elderly subjects after long-term unilateral disuse. *J Appl Physiol* 2004;97:1954-1961.

Sullivan DH, Roberson PK, Smith ES, Price JA, & Bopp MM. Effects of muscle strength training and megastrol acetate on strength, muscle mass, and function in frail older people. *J Am Geriatr Soc* 2007;55:20-28.

Suzuki T, Kim H, Yoshida H, & Ishizaki T. Randomized controlled trial of exercise intervention for the prevention of falls in community-dwelling elderly Japanese women. *J Bone Miner Metab* 2004;22:602-611.

Szklo M, & Nieto J. *Epidemiología intermedia. Conceptos y aplicaciones.* Madrid: Díaz de Santos, 2003:397-399.

Thelen DG, Brockmiller C, Ashton-Miller JA, Schultz AB, & Alexander NB. Thresholds for sensing foot dorsi- and plantarflexion during upright stance: effects of age and velocity. *J Gerontol A Biol Sci Med Sci* 1998;53A:M33-M38.

Thelen DG, Schultz AB, Alexander NB, & Ashton-Miller JA. Effects of age on rapid ankle torque development. *J Gerontol A Biol Sci Med Sci* 1996;51:226-232.

Thompson PD, Buchner D, Piña IL, Balady GJ, Williams MA, Marcus BH, Berra K, Blair SN, Costa F, Franklin B, Fletcher GF, Gordon NF, Pate RR, Rodriguez BL, Yancey AK, & Wenger NK. Exercise and physical activity in the prevention and treatment of atherosclerotic cardiovascular disease. *Arterioscler Thromb Vasc Biol* 2003;23:1319-1321.

Thorbahn LD. Value and limitations of the Berg balance test to predict risk of falls in nursing home residents. *Ann Long Term Care* 1998;6:49-53.

Tibbits GM. Patients who fall: how to predict and prevent injuries. *Geriatrics* 1996;51:24-28.

Tinetti ME. Performance-oriented assessment of mobility problems in elderly patients. *J Am Geriatr Soc* 1986;34:119-126.

Tinetti ME. Clinical practice. Preventing falls in Elderly Persons. *N Engl J Med* 2003;348:42-49.

Tinetti ME, Doucette J, Claus E, & Marottoli R. Risk factors for serious injury during falls by older persons in the community. *J Am Geriatr Soc* 1995a;43:1274-1321

Tinetti ME, Inouye SK, Gill TM, & Doucette JT. Shared risk factors for falls, incontinence, and functional dependence. Unifying the approach to geriatric syndromes. *J Am Geriatr Soc* 1995b;273:1348-1353.

Tinetti ME, Richman D, & Powell L. Falls efficacy as a measure of fear of falling. *J Gerontol B Psychol Sci Soc Sci* 1990;45B:P239-P243.

Tinetti ME, Speechley M, & Ginter SF. Risk factors for falls among elderly persons living in the community. *N Engl J Med* 1988;319:1701-1707.

Trost SG, Owen N, Bauman AE, Sallis JF, & Brown W. Correlates of adults' participation in physical activity: review and update. *Med Sci Sports Exerc* 2002;34:1996-2001.

Trueblood PR, Hodson-Chennault N, McCubbin A, & Youngclarke D. Performance and impairment-based assessments among community dwelling elderly: sensitivity and specificity. *Issues on Aging* 2001;24:2-6.

Vanhees L, Lefevre J, Philippaerts R, Martens M, Huygens W, Troosters T, & Beunen G. How to assess physical activity? How to assess physical fitness? *Eur J Cardiovasc Prev Rehabil* 2005;12:102-114.

Varas-Fabra F, Castro E, Pérula LA, Fernández MJ, Ruiz R, & Enciso I. Caídas en ancianos de la comunidad: prevalencia, consecuencias y factores asociados. *Aten Primaria* 2006;38:450-455.

Vellas BJ, Faisant C, Lauque S, Sendeihl M, Baumgartner R, & Andrieux JM. Estudio ICARE: investigación de la caída accidental. Estudio epidemiológico. In: Vellas B, Faisant C, Lauque S, editors. *Trastornos de la postura y riesgos de caída.* Barcelona: Glosa, 1996:15-28.

Vellas BJ, Wayne SJ, Romero LR, Baumgartner NR, Rubenstein LZ, & Garry PJ. One leg balance is an important predictor of injurious falls in older persons. *J Am Geriatr Soc* 1997;45:735-738.

Verrillo RT, Bolanowski SJ, & Gescheider GA. Effect of aging on the subjective magnitude of vibration. *Somatosens Mot Res* 2002;19:238-244.

Vincent KR, Braith RW, Feldman RA, Magyari PM, Cutler RB, Persin SA, Lennon SL, Gabr AH, & Lowenthal DT. Resistance exercise and physical performance in adults aged 60 to 83. *J Am Geriatr Soc* 2002;50:1100-1107.

Visser M, Kritchevsky SB, Goodpaster BH, Newman AB, Nevitt M, Stamm E, & Harris TB. Leg muscle mass and composition in relation to lower extremity performance in men and women aged 70 to 79: the Health, Aging and Body Composition study. *J Am Geriatr Soc* 2002;50:897-904.

de Vreede PL, Samson MM, van Meeteren NL, Duursma SA, & Verhaar HJ. Functional-task exercise versus resistance strength exercise to improve daily function in older women: a randomized, controlled trial. *J Am Geriatr Soc* 2005;53:2-10.

Wagensberg J. *Si la naturaleza es la respuesta ¿cuál es la pregunta?*. Barcelona: Tusquets Editores, 2002.

Wall JC, Bell C, Campbell S, & Davis J. The Timed Get-up-and-go Test Revisited: Measurement of the component tasks. *J Rehabil Res Dev* 2000;37:109-114.

Ware J, Kosinski M, & Keller SD. A 12-item short-form health survey: construction of scales and preliminary tests of reliability and validity. *Med Care* 1996;34:220-233.

Whipple RH, Wolfson LI, & Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. *J Am Geriatr Soc* 1987;35:13-20.

Whitney SL, Hudak MT, & Marchetti GF. The dynamic gait index relates to self-reported fall history in individuals with vestibular dysfunction. *J Vestib Res* 2000;10:99-105.

Whitney SL, Poole JL, & Cass SP. A review of balance instruments for older adults, *Am J Occup Ther* 1998;52:666-671.

Winograd CH, Gerety MB, Chung M, Goldstein MK, Dominguez F Jr, & Vallone R. Screening for frailty: criteria and predictors of outcomes. *J Am Geriatr Soc* 1991;39:778-784.

Winter DA, Patla AE, Frank JS, & Walt SE. Biomechanical walking pattern in the fit and healthy elderly. *Phys Ther* 1990;70:340-347.

Wolf AM, Hunter DJ, Colditz GA, Manson JE, Stampfer MJ, Corsano KA, Rosner B, Kriska A, & Willett WC. Reproducibility and validity of a self-administered Physical Activity Questionnaire. *Int J Epidemiol* 1994;23:991-999.

Wolf SL, Barnhart HX, Ellison GL, & Coogler CE. The effect of Tai Chi Quan and computerized balance training on postural stability in older subjects. *Phys Ther* 1997;77:371-381.

Wolf SL, O'Grady M, Easley KA, Guo Y, Kressig RW, & Kutner M. The influence of intense Tai Chi training on physical performance and hemodynamic outcomes in transitionally frail, older adults. *J Gerontol A Biol Sci Med Sci* 2006;61A:M184-M189.

Wolfson L, Judge J, Whipple R, & King M. Strength is a major factor in balance, gait, and the occurrence of falls. *J Gerontol A Biol Sci Med Sci* 1995;50A:M64-M67.

Woollacott MH, & Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture* 2002;16:1-14.

Woollacott MH, & Tang PF. Balance control during walking in the older adult: research and its implications. *Phys Ther* 1997;77:646-660.

World Health Organization. *Epidemiologia y prevención de las enfermedades cardiovasculares en los ancianos.* Ginebra: Informes técnicos, 1995.

Yesavage JA, Brink TL, Rose TL, Lum O, Huang V, Adey M, & Leirer VO. Development and validation of a geriatric depression screening scale: a preliminary report. *J Psychiatr Res* 1983;17:37-49.

Zhang JG, Ishikawa-Takata K, Yamazaki H, Morita T, & Ohta T. The effects of Tai Chi Chuan on physiological function and fear of falling in the less robust elderly: An intervention study for preventing falls. *Arch Gerontol Geriatr* 2006;42:107-116.

Zwick D, Rochelle A, Choksi A, & Domowicz J. Evaluation and treatment of balance in the elderly: A review of the efficacy of the Berg balance test and Tai Chi Quan. *Neuro Rehabilitation* 2000;15:49-56.

9. APPENDIX

Appendix I

Description of the most used physical performance assessment tools in the elderly population in chronological order of publication.

Romberg Test

Developer. Moritz Heinrich von Romberg, **1840** (Khasnis & Gokula, 2003).

Setting. For use in hospitals and the community.

Population. Older people and neurological patients.

Procedure. The subject is asked to stand with his feet close together, arms by the side and eyes open. The test lasts 30 seconds, and assesses quick or slow fall towards one side, both sides variably, or backwards. Any significant swaying or tendency to fall is noted. The patient is then asked to close his eyes. Other manoeuvres that may be used are looking away from the ground and asking the patient to follow the examiner's finger with his eyes as it moves rapidly from left to right or up and down. Postural sway is again noted and compared with that observed with open eyes. The degree of swaying as well as its position should be noted (swaying from ankles, hips or entire body). Romberg test is considered positive if there is significant imbalance with the eyes closed or the imbalance is significantly worsens on closing the eyes.

Length of time to carry out test. 2 minutes (depending on the number of trials).

Special equipment needed. None.

Training required. Not specified.

Acceptability to patients. Not specified but it is important to reassure the patient that he/she will be supported in case of severe imbalance.

Measure type. Observation.

Cut off points for level of risk. Not being able to maintain each position for at least 30 seconds without significant swaying is associated to postural instability.

Further testing of the tool. Reliability and validity data was not reported.

1. Lanska, 2002. Reported the use of quantitative, computer calculated Romberg's test and concluded that it is a reasonable way of measuring postural stability. It was also suggested that Romberg's test had contributed significantly to the development of mechanical modalities like computerized dynamic platform posturography for measuring postural stability.

2. Ortuño, Viosca & Baydal, 2007. Testing was performed with the posturography system NedSVE/IBV© (Biomechanical Institute of Valencia, Spain). Subjects are asked to stand on the force plate with no shoes, heels together and toes forming a 30º angle (following the graph on the force plate), and arms in full extension by the body. The

postural sway testing protocol consists of two trials of 30s with a 60s rest between both trials, maintaining the following positions: (a) subject standing on the force plate with eyes open; (b) subject standing on the force plate with eyes closed; (c) subject standing on a foam rubber mat (56.7kg/cm^{3}x9cm thick) placed on top of the force plate with eyes open; and (d) subject standing on the same foam rubber mat with eyes closed. During these tests the subjects are instructed to look straight ahead at a visual target and try to maintain balance without moving their arms or feet. Postural activity during the sway tests is quantified in terms of displacement of the centre of pressure on the feet, at a frequency of 1000Hz. The equipment's reproducibility and construct validity: ICC ranged 0.74-0.97 and r = 0.83 ($p<.05$).

Limitations. The main limitation of Romberg test when studying the vestibular-spinal function is the impossibility to determine the individual contribution of each of the three sensory information systems to maintain balance.

<u>Clinical Test for the Sensory Interaction on Balance (CTSIB)</u>

Developer. Shumway-Cook & Horak, **1986**.

Setting. Hospital, laboratory and community settings.

Population. Older people, and neurological patients.

Procedure. The CTSIB requires the subject to maintain standing balance under six different intersensory conditions that either eliminate input or produce inaccurate visual and surface orientation inputs. The technique uses combinations of three visual and two support-surface conditions. Visual conditions include the use of a blindfold for eliminating visual input and a visual-conflict dome for producing inaccurate input (peripheral vision is restricted completely at the top, bottom, and sides). The support-surface conditions include the use of any hard, flat surface, and the use of a foam that reduces the accuracy of the orientation information. A subject's postural sway while standing for a maximum of 30 seconds is observed in each of the six conditions.

Length of time to carry out test. 10 minutes.

Special equipment needed. Blindfold; visual-conflict dome; foam surface.

Training required. Yes, a physical therapist should assess the test.

Acceptability to patients. Not reported.

Measure type. *Observation* and *ordinal level of measurement*: using condition 1 (standing on hard, flat surface with eyes open) as a baseline reference, the therapist observes the patient for changes in the amount and direction of sway over the subsequent five conditions using a numeric ranking system (1 = minimal sway; 2 = mild sway; 3 = moderate sway; 4 = fall). *Quantitative assessment:* using a stopwatch to record the amount of time the subject maintains erect standing in each condition.

Cut off points for level of risk. Postural instability while wearing the visual-conflict dome suggests abnormal reliance on vision for posture control. Marked increases in sway or falls under conditions of sensory conflict may indicate a sensory interaction problem.

Further testing of the tool.

1. Cohen, Blatchly & Gombash, 1993. N = 62. Test-retest and interrater reliability were r = .99 (p<.01). Group 1 (25-44 years), group 2 (45-64 years), group 3 (65-84 years), and group 4 (30-87 years with diagnosed vestibular disorders). On condition 5 (eyes closed on the foam) group 3 had scores significantly lower than those of groups 1 and 2, but not significantly different from those on group 4. Although group 3 performed significantly worse than groups 1 and 2 on condition 6 (foam and dome), the scores of group 3 were significantly higher than those of group 4.

Limitations. Although the CTSIB data set can document the presence of sensory dysfunction, it cannot provide impairment information specific to an individual sensory system. The information provided is designed to help the clinician assess the need for further testing in patients with complaints related to balance dysfunction, and to establish objective baselines for treatment planning and outcome measurement.

Performance Oriented Mobility Assessment (POMA or Tinetti scale)

Developer. Tinetti, **1986**.

Setting. Aimed at all settings.

Population. Ambulatory elderly.

Procedure. The short form graded the ability to perform 9 common everyday movements. The clinical balance and gait performance of the long form consists of grading the steadiness of the subject in performing the following 13 balance tasks: sitting, rising from a chair, standing immediately upon rising, prolonged standing with eyes open, standing with eyes closed, withstanding a nudge on the chest, turning in a circle 360º, turning the head, standing on one leg for 5 seconds, bending down, reaching up, sitting down, and several qualitative aspects of the locomotion pattern.

Length of time to carry out test. 10 minutes.

Special equipment needed. Stopwatch; chair; 5lb object; 15ft walkway.

Training required. Yes, assessment by professional.

Acceptability to patients. Not reported.

Measure type. *Observation* and *ordinal level of measurement*: using a 0-2 numeric ranking system (0 = most impairment; 2 = independence). Short form scale 0-28, and long form scale 0-40.

Cut off points for level of risk.

Clinical experience and judgement. >18 (short form) is stated as a cut off point that predicts falls (Tinetti, 1986).

Further testing of the tool.

1. Whitney, Poole & Cass, 1998**.** Interrater reliability: 85% ± 10%, and concurrent validity: Berg balance scale r = 0.91; predictive (short form) >18 predicted falls.

2. Raîche et al., 2000. N = 225 community dwelling participants (Canada).

Cut off score = 36 or less: sensitivity = 70%; specificity = 52%.

3. Perell et al., 2001. Refers to Tinetti et al. (1986). In and out patients. Cut off point of 10 (short form): sensitivity = 80%; specificity = 74%.

4. Salvà et al., 2005. N = 443 community-dwelling people older than 65 (Spain). 29.3% of subjects did not present abnormalities in any of the items, 22.6% presented one abnormality, 12.4% two, and 35.7% three or more. 35.9% and 50.2% of subjects did not present abnormalities in the static and dynamic components respectively. Women had greater number of mistakes than men (42% versus 20.6%). A higher number of mistakes correlated with lower independence in daily life activities, less physical activity, worse self-perception of health, and more previous falls.

Limitations. Generally these were narrative reviews with a clear emphasis on specific tests and scales. Limited information is given regarding the quality of studies, demographic information, which provided the data source for the review.

Berg Balance Scale (BBS)

Developer. Berg et al., **1989**.

Setting. All settings. Previous testing includes elderly care home, acute care settings and laboratory.

Population. Ambulatory elderly.

Procedure. Grading the ability to perform 14 common everyday movements: ability to maintain positions of decreasing stability; to change positions; perform tasks in unstable positions; perform movements with increasing speed. Components include balance, lower and upper extremity strength. The aspects of balance measured are: sit to stand, stand to sit, stand and sit unsupported, transfer bed to chair, stand eyes closed, stand feet together, standing one foot in front of other, reach forward, pick up object from floor, single leg stance, look over shoulders, turn 360º, and alternate foot on stool.

Length of time to carry out test. 15 minutes.

Special equipment needed. Stopwatch; chair; bed; ruler; stool.

Training required. Yes, assessment by professional.

Acceptability to patients. Not reported.

Measure type. *Observation* and *ordinal level of measurement*: using a 0-4 numeric ranking system (0 = most impairment; 4 = doing the task as normal). Scale 0-56 points, divided into sub-scales.

Cut off points for level of risk.

Clinical experience and judgement. 45 is stated as a cut off point.

Further testing of the tool.

1. Berg et al., 1992. Extended setting n=113 participants.

Interrater reliability: caregiver and participants gave a global rating scale score of their balance ability (good, fair, poor). Four data points: initial assessment, 3, 6 and 9 months.

Results (Pearson product moment correlation coefficient): Caregiver ratings and BBS: r = 0.47 to 0.61; self-rating and BBS r = 0.39 to 0.41.

Concurrent validity: Researchers assessed participants with BBS and functional independence with the Barthel index (BI) (Mahoney & Barthel, 1965). BBS cut-off point of 45 or greater determined those who are safe in independent ambulation based on clinical experience.

Results (Pearson product moment correlation coefficient): BBS and BI: r=0.87 to 0.93.

Predictive validity: at one year follow-up participants were classified according to fall status.

Results (Relative risk 95%CI): Score of less than 45: RR 2.7 (1.5-4.9).

2. Whitney et al., 1998. Interrater reliability: ICC = 0.98; interrater rs = 0.88; internal consistency/ Cronbach's alpha = 0.96.

Concurrent validity: Barthel Index: r = 0.67; Timed up and Go: r = 0.76; Tinetti: r = 0.91.

Predictive validity: <45 predicted falls

3. Thorbahn, 1998. As above, predictive validity: Cut off point of 45 described for one study, other not stated. In both studies participated community dwelling and sample size less than 70. Sensitivity range = 53% to 91%; specificity range = 82% to 96%

Suggests that further research is needed on individuals who score between 31 and 45.

4. Zwick et al., 2000. Refers to the following study not included in the above:

Harada et al., 1995. N= 53 extended care participants. Cut off point of 48, sensitivity=84%; specificity=78%.

5. Perell et al., 2001. Refers to Berg et al., 1989. Outpatient and CVA patients. Cut off point of 49; sensitivity = 77%; specificity = 86%.

6. Muir et al., 2008. The BBS had good discriminative ability to predict multiple falls when ROC analysis was used. However, the use of the BBS as a dichotomous scale, with a threshold of ≤45, was inadequate for the identification of the majority of people at risk for falling in the future, with sensitivities of 25% and 45% for any fall and for multiple falls, respectively. The use of likelihood ratios, maintaining the BBS as a multilevel scale, demonstrated a gradient of risk across scores, with fall risk increasing as scores decreased.

Limitations. Limited information is given regarding the quality of studies, demographic information, which provided the data source for the review. No dual-task assessment, and quite long to administer.

<u>Functional Reach Test (FRT)</u>

Developer. Duncan et al., **1990**.

Setting. All settings.

Population. Ambulatory elderly.

Procedure. Measurement in inches/cm of the distance between arm's length and maximal forward reach using a fixed base of support.

Length of time to carry out test. Two minutes.

Special equipment needed. A yardstick or a force platform/ electronic system for measuring functional reach.

Training required. Yes.

Acceptability to patients. Not reported.

Measure type. Inches/ centimetres.

Cut off points for level of risk. Developmental study by the authors indicate that a reach of less than or equal to six inches (15 cm) are very fragile, limited in their daily life activities, and have a higher risk of falls.

Further testing of the tool. Interrater reliability on reach measurement reported as 0.92.

1. Eagle et al., 1999. Inpatients therefore excluded.
2. Dite & Temple, 2002 (Australia). N = 81 community dwelling participants. Concurrent validity: FRT/TUGT rs = -0.47; FRT/Step test rs = 0.50.
3. Behrman et al., 2002 (USA). Case control study, inpatients therefore excluded.

Limitations. Only assesses ability to reach forward and no other balance or performance.

<u>Timed Up and Go Test (TUGT)</u>

Developer. Podsiadlo & Richardson, **1991.**

Setting. All settings.

Population. Ambulatory elderly.

Procedure. Subjects are asked to stand up from sitting on a chair, walk for 3 metres at a normal speed, turn around, go back to the chair, and sit down again. Every subject has to do the test once on trial and then twice being timed.

Length of time to carry out test. Five minutes.

Special equipment needed. Stopwatch; chair; 3m walkway.

Training required. Yes.

Acceptability to patients. Not reported.

Measure type. Measurement of *time* to complete the test. *Ordinal level of measurement:* 5 point rating scale of observer's perception of patient's risk of falling (1 = normal, not at risk of falling; 5 = severely abnormal).

Cut off points for level of risk. 10-14 seconds.

Further testing of the tool.

1. Podsiadlo & Richardson, 1991. N = 60 community dwelling participants attending day hospital (Canada). Interrater/ intrarater reliability = ICC 0.99. Concurrent validity: TUGT/ BBS r = -0.81; TUGT/ Gait speed r = -0.61; TUGT/ Barthel r = -0.78.
2. Whitney et al., 1998. Refers to Podsiadlo & Richardson (1991) as above, and Okumiya et al. (1998) (Japan). Community dwelling. Cut off time 16 seconds: sensitivity = 54%; specificity = 74%; PPV 44%.
3. Perell et al., 2001. Refers to Shumway-Cook et al. (2000). N = 30 outpatient setting. Interrater reliability 0.98. Cut off time 14 seconds: sensitivity and specificity = 87%.
4. Trueblood et al., 2001 found that the time limit that distinguishes people at risk of falls from those without risk was 10-12 seconds.
5. Dite & Temple, 2002. N = 81 community dwelling participants. Concurrent validity: TUGT/ FSST rs = 0.88; TUGT/ Step test rs = -0.79; TUGT/ FRT rs = -0.47.
6. Rose, Jones & Lucchese, 2002. N = 134 community dwelling participants (USA). Cut off time 10 seconds: sensitivity = 71%; specificity = 89%.

Limitations. Limited information is given regarding the quality of studies, and demographic information, which provided the data source for the review. Not able to assess each task separately, and no dual-task assessment.

<u>Short Physical Performance Battery (SPPB or Guralnik Test)</u>

Developer. Guralnik et al., 1994.

Setting. All settings.

Population. Community elderly.

Procedure. Instrument that measures balance, gait, strength, and resistance by examining the ability to keep the three following positions for 10 seconds: tandem stance (heel of one foot directly in front of the other foot), semi-tandem (heel of one foot beside the big toe of the other foot), and side-by-side stands. Timing is stopped when participants move their feet, or when 10 seconds have elapsed. Those unable to hold the semi-tandem position for 10 seconds are evaluated with the feet in side-by-side position. Those able to maintain the semi-tandem position for 10 seconds are further evaluated with the feet in full tandem position. Time required to walk for 8 feet is also examined in two trials to derive the gait speed, as well as time required to get up and sit down on a chair 5 times.

Length of time to carry out test. 12 minutes.

Special equipment needed. Stopwatch; chair.

Training required. Yes.

Acceptability to patients. Not reported.

Measure type. Measurement of *time* to complete the tests.

Cut off points for level of risk. Guralnik et al. (1995): for *tests of standing balance* the subjects were given a score of 1 if they could hold a side-by-side standing position for 10 seconds but were unable to hold semi-tandem position for 10 seconds; a score of 2 if they could hold a semi-tandem position for 10 seconds but were unable to hold a full tandem position for more than 2 seconds; a score of 3 if they could stand in the full tandem position 3-9 seconds; and a score of 4 if they could stand in full tandem position for 10 seconds). For the *walking test*: a score of 1 = ≥5.7 seconds; a score of 2 = 4.1-5.6 seconds; a score of 3 = 3.2-4.0 seconds; and a score of 4 = ≤3.1 seconds. For the *sit-to-stand test*: a score of 1 = ≥16.7 seconds; a score of 2 = 13.7-16.6 seconds; a score of 3 = 11.2-13.6 seconds; and a score of 4 = ≤11.1 seconds.

Further testing of the tool. Spearman correlation coefficients: walking and chair stands 0.48; walking and standing balance 0.39; chair stands and standing balance 0.39 ($p<.001$). Cronbach's alpha = 0.76. $R^2 = 0.46$.

Limitations. No assessment of upper extremity function.

Dynamic Gait Index (DGI)

Developer. Shumway-Cook & Woollacott, **1995**.

Setting. All settings.

Population. Ambulatory elderly.

Procedure. This test uses 8 items to measure an individual's ability to adapt to environmental, speed and head position changes during gait. The different tasks are assessed with a 0-3 scale (0 = inability; 3 = normal performance). The highest final score is 24 points. Assessment is based on the subject's ability to keep a normal gait rhythm and to keep walking on a 38.1-cm wide path without tripping or losing balance during gait. Subjects are asked to walk faster or slower, with head upright or bent forwards, walk on or by some objects, and go up and down stairs.

Length of time to carry out test. 15 minutes.

Special equipment needed. Stairs.

Training required. Yes.

Acceptability to patients. Not reported.

Measure type. *Ordinal level of measurement*: 0-3 point rating scale of observers judgement (0 = inability/ severe impairment, 3 = normal). Total score 24.

Cut off points for level of risk. Initial development by the authors using a small sample (n = 44) of community dwelling participants. Using a cut off value of <19 the DGI identified 64% of the non fallers from previous history of falls. No further data extracted due to sample size.

Further testing of the tool.

1. Whitney et al., 2000 (USA). N = 247 outpatients referred for treatment of vestibular dysfunction. Falls history obtained from participants. DGI scores of 19 or lower/ falls = OR 2.58 (1.47-4.53).

2. Perell et al., 2001. Refers to Whitney et al. (2000) as above.

Limitations. Assesses all aspects of gait but longer to administer.

Single-leg balance time (SLB)

Developer. Vellas et al., **1997**.

Setting. All settings.

Population. Community-dwelling elderly people.

Procedure. Participants are asked to place their hands across their chest, lift their preferred leg, and stand for as long as possible. Subjects should stand with their lifted foot approximately 5 cm from the medial malleolus of the stance foot without the lifted foot being in contact with the malleollus. Those participants who can stand for more than 30 seconds (excellent balance) are asked to stop the test.

Length of time to carry out test. 2 minutes.

Special equipment needed. Stopwatch.

Training required. No.

Acceptability to patients. 84.5% of n = 316 subjects could perform the test.

Measure type. Measurement of *time* to complete the test.

Cut off points for level of risk. An individual is considered to be at high risk of falls when unable to stand for at least 5 seconds.

Further testing of the tool. Cut off time 5 seconds to predict an injurious faller: sensitivity = 6%; specificity = 76%. Impaired one-leg balance/ predictor of injurious falls = RR 2.13 (1.04-4.34) (p = 0.03).

1. Menéndez-Colino et al., 2005. They concluded by saying that subjects that are able to carry out this one-foot stance for at least 5 seconds have a lower risk of falls than those who are unable.

Limitations. The study population was volunteers not representative of the population. Moreover, the determination of single stance was dichotomized at 5 seconds rather than used as a continuous variable which would have provided considerably more data and possibly improved the predictive relationship.

Maximal Step Length (MSL) and Rapid Step Time (RST)

Developer. Medell & Alexander, **2000.**

Setting. All settings.

Population. Community-dwelling elderly people.

Procedure. The MSL test assesses the ability to do the longest step possible and in different directions (left, right, forward, and backward), and to be able to go back to initial position, with arms folded on chest. The RST assesses time required to take a certain number of steps, always going back to initial position in different directions and as fast as possible.

Length of time to carry out test. 15 minutes.

Special equipment needed. Stopwatch; tape-measure.

Training required. Yes.

Acceptability to patients. Not reported.

Measure type. Measurement of *time* and *length*.

Cut off points for level of risk. Not reported.

Further testing of the tool. Same-day and within-week *reliability* for RST ranged from 0.71-0.97 and 0.80-0.91 respectively. Within-week *reliability* for MSL ranged from 0.87-0.90. Interrater reliability for RST r = 0.98. *Concurrent validity*. MSL/ SLB r = 0.84; RST/ SLB r = -0.81.

1. Cho, Scarpace & Alexander, 2004. N = 168 mildly-balanced impaired older adults. Measures of MSL and RST were compared to tandem stance (TS), tandem walk (TW), SLB, TUGT, POMA, 6 minute-walk (6MW), leg strength (LG). MSL/ TUGT, 6MW, POMA range 0.58-0.75 (p<0.01); MSL/ TS, SLB, TW range 0.38-0.74 (p<0.01); RST/ comparison tests range 0.15-0.38.

Limitations. The assessment is limited to step length and reaction time; no assessment of balance, strength and upper extremity function.

Turn 180º

Developer. Simpson et al., **2002**.

Setting. For use in hospitals and the community.

Population. Older people, particularly those around 75 years with complex problems.

Procedure. Older people are prepared with comfortable and suitable clothing and footwear. Stable handholds are made available. A suitable chair that requires minimal effort to stand up by the older person is provided. For comparability, all future tests need to be conducted in similar conditions – for example, time of day, same observer and setting. Instructions for the older person may need to be repeated to ensure they have understood. Instructions could be written on a card so that they may be read.

The older person needs to stand up and, on request, turn to face the opposite direction, without holding onto chairs, if possible. They must try not to use objects to support their body weight, as this would invalidate the test. They can choose the direction in which they turn. An observer behind the older person counts the steps taken.

Length of time to carry out test. The test is not timed and the subject may take as long as they require.

Special equipment needed. None.

Training required. Not specified, however the practice of standardising this test is attempting to eliminate errors of judgement on the part of the assessors.

Acceptability to patients. Devised for the frail older person, the development of the standardised procedure evaluated fear where the majority (87.3%) did not experience fear of falling during the test.

Measure type. Observation and counting of steps taken to turn 180°.

Cut off points for level of risk. More than four steps are associated with an increased fall risk (Nevitt et al., 1989).

Further testing of the tool.

1. Nevitt et al., 1989. The aim of this study was to ascertain risk factors for recurrent falls. Outcome measurement was taken of the number of steps to complete a 180° turn. No procedure is given for the test. This was a single sample prospective cohort of N = 325 community dwelling older people above 60 years, with a history of one previous fall in the last 12 months. The mean number of steps taken was 4±2. The unadjusted RR 1.9 (1.2-3.2) for greater than five steps to make the turn was associated with an increased risk of multiple falls (two or more).
2. Simpson et al., 2002. The aim of this study was to describe the development of a standardised procedure for the 180° turn. Patients admitted to acute geriatric wards were screened for eligibility as soon as their discharge date was set. N = 142 patients with a mean age of 81 years completed the tests (two tests turning clockwise or anti-clockwise). Turn 180º step counts correlated positively with number of falls recalled in the last 6 months (rho = 0.35, p = 0.001).

Limitations. The assessment is limited to balance.

Appendix II

Interventions to reduce functional decline in older adults and in frail older adults.

Study	Methods	Population/ setting	Interventions	Results
Lichtenstein et al., 1989	Quasi randomized controlled trial. Method of randomization: Random Number table to recruit participants from sample then group randomized by apartment building n = 2 by coin toss. Assessors blinded. Losses: 7 of 50	N = 50 Age: mean 76.7 Sex: Female Setting: USA Inclusion: Women, 65 years or older, single (never married, divorced, separated, widowed) and living alone. Exclusion: History of Parkinson or Stroke, had any loss of limb, were unable to walk independently or with use of cane.	Exercise group (GBFT): stretching, “static balance” (e.g. standing on one leg), “active balance” (e.g. using tandem heel/toe gait, walking along a line), “response exercises” (e.g. performing manoeuvres in response to changing colour signals), walking and cool-down and relaxation. Control group: usual activity. Duration and intensity: sessions were 60 minutes, 3 x week for 16 weeks. Supervisor: investigator Supervision: group Setting: community Outcomes: Single legged stance - eyes open, eyes closed on force platform. Average XY area per second (square inches/s). Average radial area per second (square inches/s). Average velocity (inches/s).	After 16 weeks, in stances on one foot, exercisers had smaller areas compared to controls with eyes open, but larger areas with eyes closed. Subgroup analysis indicated that compliance with the exercise program was a determinant of degree of change in the area measures. The inconsistent effect of exercise on area measures of sway in this study may be due to (a) lack of statistical power to detect between-group differences, (b) inadequate compliance with the exercise program, (c) baseline differences between the two groups at randomization, and (d) ineffective or inadequate duration of the exercise program. Controlled clinical trials to study the effect of exercise on balance measures in community-dwelling elderly women are feasible.
Fiatarone et al., 1994	Randomized, placebo-controlled trial.	N = 100 frail nursing home residents. Age: 87.1 ± 0.6 years. Inclusion: residential status, an age over 70 years, and the ability to walk 6m. Exclusion: severe cognitive impairment, rapidly progressive or terminal illness, acute illness or unstable chronic illness, myocardial infarction, fracture of a lower extremity within the six months before the study, or insulin-dependent diabetes mellitus; if they were on a weight-loss diet or undergoing resistance training at the time of enrolment; or if tests of muscle strength revealed a musculoskeletal or cardiovascular abnormality.	Progressive resistance exercise training of high-intensity progressive resistance training of the hip and knee extensors 3 days per week for 10 weeks. Multinutrient supplementation once each day in the evening for 10 weeks. Both interventions. Control: neither intervention. Outcomes: Katz Activities of Daily Living Index; Mini-Mental State Examination; Geriatric Depression Scale; maximal weight that could be lifted correctly for one repetition only was used as the measure of dynamic concentric muscle strength in the hip and knee extensors; gait velocity; habitual dietary intake.	63 women and 37 men enrolled in the study and 94 percent of the subjects completed the study. Muscle strength increased by 113 ± 8 percent in the subjects who underwent exercise training, as compared with 3 ± 9 percent in the nonexercising subjects (P<0.001). Gait velocity increased by 11.8 ± 3.8 percent in the exercisers but declined by 1.0 ± 3.8 percent in the nonexercisers (P = 0.02). Stair-climbing power also improved in the exercisers as compared with the nonexercisers (by 28.4 ± 6.6 percent vs. 3.6 ± 6.7 percent, P = 0.01), as did the level of spontaneous physical activity. Cross-sectional thigh-muscle area increased by 2.7 ± 1.8 percent in the exercisers but declined by 1.8 ± 2.0 percent in the nonexercisers (P = 0.11). The nutritional supplement had no effect on any primary outcome measure. Total

				energy intake was significantly increased only in the exercising subjects who also received nutritional supplementation.
Lord et al., 1995	Randomized controlled trial. Prerandomization prior to consent, from a schedule of participants in a previous study. All from intervention group. Inadequate data for intention to treat analysis.	Setting: community, Australia. N=194. Sample: women, recruited from a schedule from a previous epidemiologic study. Fitness level not defined. Age: range 60-85 years (mean (SD) 71.6 ± 5.4 years. Inclusion criteria: living independently in the community. Exclusion criteria: unable to use English.	a. Exercise group (MULTIPLE): improving strength, flexibility, co-ordination, and balance, the individualised exercise regimes were based on participant's falls risk profile. Twice weekly exercise programme (warm up, conditioning, stretching, relaxation) lasting one hour, over a 12-month period. b. Control: no intervention.	Measured over 12 months. Fall ascertainment questionnaires sent out every two months. Telephone call if questionnaire not returned. Losses: 19 of 194 (10%). Outcomes 1. Number of participants falling. 2. Number of participants sustaining two or more falls. 3. Number of participants sustaining one or more falls indoors. 4. Number sustaining nonaccidental falls. 5. Number sustaining 'balance falls'. Results Exercise/physical therapy alone vs control, community dwelling untargeted: 1. Number of participants falling, n=26/75 vs 33/94 RR 0.99 [0.65, 1.50]. 2. Number sustaining two or more falls, n=8/75 vs n=12/94 RR 0.84 [0.36, 1.94].
Wolf et al., 1997	Randomized controlled trial. Randomized using computer generated procedure. Inadequate data for intention to treat analysis.	Setting: community, Atlanta, USA. N=200. Sample: men (N=38) and women (N=162) residing in an independent living facility, recruited by local advertisements and direct contact. Age: 76.9 ± 4.8 years for intervention a, 76.3 ± 5.1 for intervention b, and 75.4 ± 4.1 for controls. Inclusion criteria: above 70 years old; ambulatory; living in unsupervised environment; agreeing to participate on a weekly basis for 15 weeks with four month follow-up. Exclusion criteria: debilitating conditions e.g. cognitive impairment, metastatic cancer, crippling arthritis, Parkinson's	a. Tai Chi Quan (balance enhancing exercise). Group sessions twice weekly, for 15 weeks (individual contact with instructor approximately 45 minutes per week). b. Computerised balance training. Individual sessions once weekly, for 15 weeks (individual contact with instructor approximately 45 minutes per week). c. Control: group discussions of topics of interest to older people with gerontological nurse, one hour once weekly for 15 weeks.	Length of follow-up seven - 20 months. Falls ascertained by monthly calendar or by monthly phone call from project staff. Used modified definition of a fall rather than agreed definition for FICSIT trials described in Buchner et al. (1993). Losses: 40 of 200 (20%). Outcomes 1. Number of falls. 2. Time to one or more falls. 3. Time to one or more injurious falls. Results 15 week Tai Chi intervention vs control, participants falling RR 0.51 [0.36, 0.73]. When using a narrower definition of falling excluding stumbling RR 0.67 [0.41, 1.09].

		disease, major stroke, profound visual defects.		
Buchner et al., 1997	Randomized controlled trial. Randomized by 'variation of randomly permuted blocks'. Randomized to seven groups: six intervention groups (three FICSIT, three MoveIT), and one control group. Only FICSIT and control groups reported in this paper. Intention to treat analysis.	Setting: community, Seattle, USA. N=105. Sample: HMO members (FICSIT intervention groups only). Age: mean 75 years. Inclusion criteria: aged between 68 and 85 years; unable to do eight step tandem gait test without errors; below 50th percentile in knee extensor strength for height and weight. Exclusion criteria: active cardiovascular, pulmonary, vestibular, and bone disease; positive cardiac stress test; body weight >180% ideal; major psychiatric illness; active metabolic disease; chronic anaemia; amputation; chronic neurological or muscle disease; inability to walk; dependency in eating, dressing, transfer or bathing; terminal illness; inability to speak English or complete written forms.	Supervised exercise classes one hour x three days per week for 24-26 weeks, followed by unsupervised exercise. a. Six months endurance training (ET) (stationary cycles) with arms and legs propelling wheel. b. Six months strength training (ST) classes (using weight machines for resistance exercises for upper and lower body). c. Six months ST plus ET. d. Control: usual activity levels but 'allowed to exercise after six months'. Exercise sessions started with a 10 to 15 minute warm up and ended with a five to 10 minute cool down.	Length of follow-up: variable, from randomisation to the end of study funding (0-25 months, median 18 months). Losses: 15 of 105 (14%) (14 from intervention groups). <u>Outcomes</u> Fall outcomes reported for any exercise (all three groups combined) compared with control group (states 'a priori decision'). Falls reported immediately by mail, also monthly postcard return; telephone follow-up if no postcard received. 1. Number of fallers at 1 year. 2. Time to first fall. 3. Number of falls per person. <u>Results</u> Exercise/physical therapy alone n=32/75 vs control n=18/30, number of participants falling community dwelling untargeted RR 0.71 [0.48, 1.05].
Campbell et al., 1997	Randomized controlled trial. Allocation schedule developed using computer generated numbers. Assignment by independent person off site. Intention to treat analysis.	Setting: community, Dunedin, New Zealand. N=233. Sample: women identified from general practice registers. Age: 84.1 ± 3.1 years. Inclusion criteria: at least 80 years old; community living. Exclusion criteria: cognitive impairment; not ambulatory in own residence; already receiving physiotherapy.	Baseline health and physical assessment for both groups. a. One hour visits by physiotherapist x four in first two months to prescribe home based individualised exercise and walking programme. Exercise 30 minutes x three per week plus walk outside home x three per week. Encouraged to continue for one year. Regular phone contact to maintain motivation after first two months. b. Control: social visit by research nurse x four in first two months. Regular phone contact.	Length of follow-up: 12 months and 24 months. Losses: 20 of 233 (9%). <u>Outcomes</u> Falls recorded daily on postcard calendars, mail registration monthly by postcard, telephone follow-up. 1. Number of participants falling at one year and two years. 2. Number with injury fall at one and two years. 3. Number with two or more falls. 4. Mean rate of falls (falls/per year). 5. Fall rate per 100 person years. 6. Number complying with intervention. <u>Results</u> Exercise/physical therapy alone n=53/116 vs control 62/117 number of participants falling, community dwelling (strength, balance, walking)- individually targeted RR 0.86 [0.66,

				1.12]. Exercise/physical therapy alone n=27/103 vs control n=43/110 1. Number of participants sustaining injury fall, community dwelling – individually targeted RR 0.67 [0.45, 1.00]. 2. Number sustaining two or more falls n=22/116 vs 34/117 RR 0.65 [0.41, 1.05].
Fiatarone et al., 1997	Randomized controlled trial. Method of randomization not described. No intention to treat analysis.	Setting: community, USA. N=34. Sample: frail older people (94% female). Age: mean 82. Inclusion criteria: community dwelling older people; moderate to severe functional impairment. Exclusion criteria: none given.	a High intensity progressive resistance training exercises in own home. Two weeks of instruction and then weekly phone calls. 11 different upper and lower limb exercises with arm and leg weights, three days per week for 16 weeks. b. Control: wait list control. Weekly phone calls.	Length of follow-up 16 weeks (duration of intervention). Falls identified weekly by phone (assumed). Losses: four of 34 (11%). <u>Outcomes</u> 1. Falls. 2. Strength, gait velocity, and self reported activity level. 3. Attitude towards ageing on the PGC morale scale, bed days, health care visits. <u>Results</u> No difference between groups was observed in the frequency of falls in this study. No summary statistic and no data provided.
Cerny et al., 1998	Randomized controlled trial. Randomized by coin toss but some clusters, for example couples or two ladies dependent on another for transport. Intention to treat analysis not possible.	Setting: community, California, USA. N=28. Sample: community dwelling well elderly. Age: 71 ± 4 years. Inclusion criteria: none described. Exclusion criteria: none described.	a. Exercise programme of progressive resistance, stretching, aerobic and balance exercises and brisk walking over various terrains for 1½ hours, x weekly, for six months. b. Control: no intervention.	Follow-up at three and six months Losses: none described. <u>Outcome</u> 1. Number of participants falling. <u>Results</u> Exercise/physical therapy alone vs control community dwelling untargeted. Number of participants falling n=3/15 vs n=3/13 RR 0.87 [0.21, 3.58].
Pereira et al., 1998	Randomized controlled trial 1982-85. Reporting 10-year follow-up. Intention to treat analysis not possible.	Setting: community, Pittsburgh, USA N=229 randomised – 198 available for 10-year follow-up. Sample: healthy volunteers. Age: mean 57 years at randomisation. Mean ± SD at follow-up 70 ± 4 years. Inclusion criteria: one year postmenopausal; aged between 50 and 65 years. Exclusion criteria: on HRT; unable to	a. Eight week training period with organised group walking scheme x two weekly. Also encouraged to walk x once weekly on their own. Building up to seven miles per week total. b. Control: no intervention.	Reporting 10-year follow-up. Falls in the previous 12 months ascertained by telephone interview. Losses: 31 of 229 (14%). <u>Outcomes</u> 1. Number of participants falling. 2. Number sustaining two or more falls. 3. Self-reported walking. 4. Functional status. 5. Sport and exercise index. 6. Chronic diseases and conditions.

		walk.		Results Exercise/physical therapy alone vs control, community dwelling untargeted 1. Number of participants falling, n=26/96 vs n=33/10 RR 0.82 [0.53, 1.26]. 2. Number sustaining two or more falls, n=22/96 vs n=30/100 RR 0.76 [0.48, 1.23].
Campbell et al., 1999	Randomized controlled trial, two by two factorial design. Allocation schedule developed using computer generated numbers. Assignment by independent person off site. Intention to treat analysis.	Setting: community. Dunedin, New Zealand. N=93. Sample: men (N=22) and women (N=77) identified from general practice registers. Age: 74.7 ± 7.2 years. Inclusion criteria: at least 65 years old; currently taking a benzodiazepine, any other hypnotic, or any antidepressant or major tranquillizer; ambulatory in own residence; not receiving physiotherapy; thought by GP to benefit from psychotropic medication withdrawal. Exclusion criteria: cognitive impairment.	Baseline assessment. a. Gradual withdrawal of psychotropic medication over 14-week period plus home based exercise programme. b. Psychotropic medication withdrawal with no exercise programme. c. No change in psychotropic medication plus exercise programme. d. No change in psychotropic medication and no exercise programme. Exercise programme: one hour physiotherapist visits x four in first two months to prescribe home-based individualised exercises (muscle strengthening and balance retraining exercises 30 min x three per week) and walking x two per week. Regular phone contact to maintain motivation. Study capsules created by grinding tablets and packing into gelatine capsules. Capsules containing inert and active ingredients looked and tasted the same.	Length of follow-up: 44 weeks. Losses: 21 of 93 (23%). Outcomes Falls recorded daily on postcard calendars, mail registration monthly by postcard, telephone follow-up. 1. Number of participants falling. 2. Number sustaining medical care fall. 3. Number sustaining fracture fall. 4. Number sustaining injury fall. 5. Number sustaining two or more falls. 6. Number sustaining one or more falls indoors. 7. Fall rate per 100 person years. 8. Number sustaining an adverse effect. 9. Number who complied with intervention. Results Exercise/physical therapy alone vs control community dwelling individually targeted: 1. Number of participants falling community dwelling (strength, balance, walking)-individually targeted: N=12/45 vs n=16/48 RR 0.80 [0.43, 1.50]. 2. Number sustaining medical fall: N=3/45 vs 4/48 RR 0.80 [0.19, 3.38]. 3. Number sustaining fracture fall: N=1/45 vs n=0/48 RR 3.20 [0.13, 76.48]. 4. Number sustaining injury fall, n=5/45 vs 8/48 RR 0.67 [0.24, 1.89]. 5. Number sustaining two or more falls: n=5/45 vs 7/48 RR 0.76 [0.26, 2.23]. Exercise plus medication withdrawal vs control community dwelling individually targeted: 1. Number of participants falling: n=6/24 vs 11/24 RR 0.55 [0.24, 1.24]. 2. Number sustaining medical care fall:

				n=2/24 vs 3/24 RR 0.67 [0.12, 3.64]. 3. Number sustaining fracture fall: n=1/24 vs 0/24 RR 3.00 [0.13, 70.16]. 4. Number sustaining injury fall: n=2/24 vs 3/24 RR 0.67 [0.12, 3.64]. 5. Number sustaining two or more falls: n=3/24 vs 6/24 RR 0.50 [0.14, 1.77]. Medication withdrawal vs control community dwelling individually targeted: 1. Number of participants falling: n=11/48 vs 17/45 RR 0.61 [0.32, 1.15]. 2. Number sustaining medical care fall: n=3/48 vs 4/45 RR 0.70 [0.17, 2.97]. 3. Number sustaining a fracture fall: n=1/48 vs 0/45 RR 2.82 [0.12, 67.40] 4. Number sustaining injury fall: n=7/48 vs 6/45 RR 1.09 [0.40, 3.01]. 5. Number sustaining two or more falls: n=4/48 vs 8/45 RR 0.47 [0.15, 1.45].
Cress et al., 1999	RCT. Method of randomisation not known. Blinding not known. Losses: 7 of 56. Intention to treat analysis.	N = 56 Age: 76 ± 4 years. Sex: not stated. Setting: USA. Inclusion: 70 years and above, good health, living in retirement community or apartment. Exclusion: unstable cardiovascular or metabolic disease, recent unhealed fractures, other disorders, life expectancy less than 1 year, excessive alcohol, non English speaking.	Exercise group (STRENGTH): combined endurance and resistance. Control group: none exercising. Duration and intensity: 1 hour x 3 per week for 6 months. Supervisor: not stated. Supervision: group. Setting: community. Outcomes: Usual walking speed (m/s). Time on 9 m beam (s). FRT (cm).	Compared to the Control group, the Exercise group showed significant increases in maximal oxygen consumption (11%) and muscle strength (33%). No significant differences were found between groups for changes in the Sickness Impact Profile, SF-36 scales, or the 6-minute walk. However, the CS-PFP score improved significantly in the Exercise group (14%, effect size 0.80).
Rubenstein et al., 2000	Randomized controlled trial. Randomized in blocks of 16-20 at three-six month intervals, using randomly generated sequence cards in sealed envelopes. Intention to treat analysis.	Setting: community, California, USA. N=59. Sample: men recruited from veterans administration ambulatory care centre (volunteers). Age: mean 74 years. Inclusion criteria: aged 70 years and older; ambulatory; with at least one fall risk factor: lower limb weakness, impaired gait, impaired balance, more than one fall in	a. Exercise group (MULTIPLE): PRE, hip, knee and ankle, endurance training bike, treadmill, indoor walking and balance training. Exercise sessions (strength, endurance and balance training) in groups of 16-20, three x 90 minute sessions per week for 12 weeks. b. Control: usual activities. Outcome: Single legged stance (s) (for max 15 s).	Follow-up for three months from randomisation. No active fall registration. Fall ascertainment for intervention group at weekly classes. Controls phoned every two weeks. Losses: 4 of 59 (7%). Outcomes 1. Number of fallers. 2. Number of falls. 3. Number sustaining injury falls. 4. Fall rate per 1000 person years.

		previous six months. Exclusion criteria: exercised regularly; severe cardiac or pulmonary disease; terminal illness; severe joint pain; dementia; medically unresponsive depression; progressive neurological disease.		Results Exercise/physical therapy, community dwelling, untargeted: 1. Number of participants falling, n=12/31 vs 9/28 RR 1.20 [0.60, 2.42]. 2. Number sustaining injury fall, n=0/31 vs 0.28 RR not estimable.
Steinberg et al., 2000	Randomized controlled trial. Cluster randomization. Four groups with approximately equal numbers formed from two or three national seniors branches. Groups randomly allocated to one of four interventions. Method of randomization not described. Intention to treat analysis.	Setting: community, Australia. N=252. Sample: volunteers from branches of National Seniors Association clubs. Age: mean age 69 years (range 51 - 87). Inclusion criteria: National Seniors Club member; aged 50 years or over, with capacity to understand and comply with the project. Exclusion criteria: none stated.	Cumulative intervention a. Intervention d. plus exercise classes designed to improve strength and balance, one hour per month, for 17 months; exercise handouts; gentle exercise video to encourage exercise between classes. b. Intervention d. plus a. plus home safety assessment and financial and practical assistance to make modifications. c. Intervention d. plus a. plus b. plus clinical assessment and advice on medical risk factors for falls. d. Control: oral presentation; video on home safety; pamphlet on fall risk factors and prevention.	Follow-up up to 17 months but varied between groups. Follow-up commenced after start of all components for each intervention. Fall calendar, marked daily, returned monthly. Telephone follow-up of reported falls and no monthly returns. Losses: 9 of 252 (4%). Outcomes 1. Time to first fall. 2. Fallers per 100 person months. 3. Falls per 100 person months. Results Cox's proportional hazards regression model used, adjusted hazard ratios comparing intervention with control ranged: For slips HR 0.35 [0.17, 0.73] to 0.48 [0.25, 0.91]. For trips HR 0.29 [0.16, 0.51] to o.45 [0.27, 0.74]. For falls 0.60 [0.36, 1.01] to 0.82 [0.51, 1.31].
Hogan, MacDonald & Betts, 2001	Randomized controlled trial. Computer generated sequence concealed in locked cabinet prior to randomization. Stratified by number of falls in previous year: 1 or >1. Intention to treat analysis.	Setting: community, Calgary, Canada. N=163. Sample: high-risk community dwelling men and women (71% women). Age: mean (SD) 77.6 (6.8). Inclusion criteria: fall in previous three months; living in the community; age 65 years and above; ambulatory (with or without aid); mentally intact (able to give consent). Exclusion criteria: qualifying fall resulted in lower extremity fracture, resulted from vigorous or high-risk activities, because of syncope or acute stroke, or while undergoing active treatment in hospital.	a. One in-home assessment by a geriatric specialist (doctor, nurse, physiotherapist or OT) lasting one-two hours. Intrinsic and environmental risk factors assessed. Multidisciplinary case conference (20 minutes). Recommendations sent to patients and patients' doctor for implementation. Subjects referred to exercise class if problems with balance or gait and not already attending an exercise programme. Given instructed about exercises to do at home. b. Control: one home visit by recreational therapist.	Length of follow-up: 12 months. Falls recorded on monthly calendars (47.8% returned). Also retrospective recall at three, six months (at visit) and 12 months (by phone). Losses: 24 of 163 (15%). Outcomes 1. Number of participants falling. 2. Number sustaining medical care fall. 3. Number sustaining injury fall. 4. Number sustaining three or more falls. 5. Time to first fall. 6. Mean number of falls per participant (SD). 7. Mean number of injurious falls. 8. Number who complied with treatment. 9. Death. Results Assessment followed by multifactorial

				intervention vs control, community dwelling targeting known fallers or fall risk factors only: 1. Number of participants falling, n=54/79 vs 61/84 RR 0.94 [0.77, 1.15]. 2. Number sustaining medical care fall, n=9/79 vs 8/84 RR 1.20 [0.49, 2.95].
Nowalk et al., 2001	Randomized controlled trial, stratified by age gender. Randomized by permuted blocks (block size = nine). Performed separately for each site. Intention to treat analysis not possible.	Setting: senior housing facilities (independent living to skilled nursing care), USA. N=112. Sample: residents of two long term care facilities (87% female). Age: mean 84 years. Inclusion criteria: resident of facility; age 65 years or more; cognitively able to be tested; ambulatory with or without assistive device; able to follow simple directions; co-operative; capable of participating in group exercises. Exclusion criteria: unable or willing to complete the baseline assessments.	a. 'Fit NB free' individualised progressive strength training and conditioning (treadmill, walking, bicycling, weight lifting) three x weekly for 13 to 28 months, depending on date of enrolment. Could also participate in control activities. b. 'Living and learning/Tai Chi' behavioural and psychotherapeutic methods to modulate fear of falling (nurse and social worker one x per month) and Tai Chi three x per week throughout programme. Could also participate in control activities. c. Control: basic enhanced programme: 'Walk-along' programme to encourage interaction between staff and residents while walking (one x per month), 'Pill talk' to discuss medications commonly used by seniors (frequency not described), 'Music and memories' using music of their past to stimulate pleasant memories (frequency not described).	Length of follow-up variable depending on time of enrolment (21.9 ± 4.6 months, range 13 -28 months). Losses: 32 of 112 (29%). Falls identified from incident reports. <u>Outcomes</u> 1. Number of participants falling. 2. Time to first fall. 3. Number who complied with programme. 4. Death during study. <u>Results</u> Reported no significant difference in number of falls between a control group and two exercise groups. No summary statistic and insufficient data to calculate one.
Robertson et al., 2001	Randomized controlled trial. Allocation schedule developed using computer generated numbers. Assignment by independent person off site. Intention to treat analysis.	Setting: community, West Auckland, New Zealand. N= 240. Sample: men and women living at home, identified from computerised registers at 17 general practices (30 doctors). Age: 80.9 ± 4.2, range 75 – 95 years. Inclusion criteria: aged 75 years and older. Exclusion criteria: inability to walk around own residence; receiving physiotherapy at the time of recruitment; not able to understand trial requirements.	a. Home exercise programme, individually prescribed by district nurse in conjunction with her district nursing duties. Visit from nurse at one week (one hour) and at two, four and eight weeks and six months (half hour) plus monthly telephone call to maintain motivation. Progressively difficult strength and balance retraining exercises plus walking plan. Participants expected to exercise three x weekly and walk two x weekly for one year. b. Control: usual care.	Length of follow-up one year. Active fall registration with daily calendars returned monthly + telephone calls. Losses: 29 of 240 (12%). <u>Outcomes</u> 1. Number of participants falling. 2. Number sustaining two or more falls. 3. Number sustaining fracture fall. 4. Number sustaining injury fall. 5. Time to first fall. 6. Mean number of falls per participant. 7. Fall rate per 100 person years. 8. Death during study. 9. Mean ± SD number of falls per year. 10. Number sustaining an adverse effect. 11. Number who complied with programme. <u>Results</u> Exercise/physical therapy alone vs control, community dwelling (strength, balance, walking)-individually targeted. 1. Number of participants falling, n=38/121 vs

				n=51/119 RR 0.73 [0.52, 1.02]. 2. Number sustaining fracture fall, n=2/121 vs 7/119 RR 028 [0.06, 1.33]. 3. Number sustaining injury fall, 27/121 vs n=39/119 RR 0.68 [0.45, 1.04]. 4. Number sustaining two or more falls, n=22/121 vs n=24/119 RR 0.90 [0.54, 1.52]. 5. Mean number of falls n= 121, 0.67 ± 1.29 vs n=119, 0.92 ± 1.80; WMD –0.25 [-0.65, 0.15].
Binder et al., 2002	Randomized controlled trial. Medical school research centre.	N = 119 (115 followed-up), 47% men, mean age: 83 ± 4 years. Community-dwelling older adults. Inclusion: meeting at least 2 of 3 frailty criteria: (i) score between 18 and 32 on the modified PPT; (ii) report of difficulty or assistance with up to two IADLs or one ADL; and (iii) achievement of a peak VO_2 between 10 and 18 mL/kg/min.	a. Intervention: multi-component training (flexibility, balance, coordination, reaction speed and strength of all major muscle groups and endurance training using treadmills, stationary bicycles, aerodyne bicycles or rowing machines), 3 x/wk for 9 months. b. Control: home exercise (low intensity) control group, 2–3 x/wk for 9 months. Outcomes: Modified PPT score, VO_2 peak, performance of ADLs as measured by the Older Americans Resources and Services instrument, and the Functional Status Questionnaire (FSQ).	ET resulted in significantly greater improvements than home exercise in three of the four primary outcome measures. Adjusted 95% confidence bounds on the magnitude of improvement in the ET group compared with the control group were 1.0 to 5.2 points for the modified PPT score, 0.9 to 3.6 mL/kg/min for VO_2 peak, and 1.6 to 4.9 points for the FSQ score.
Carter et al., 2002	Randomized controlled trial. Randomized by computer generated programme. Intention to treat not possible.	Setting: community, Vancouver, Canada. N=93. Subjects: community dwelling osteoporotic women. Inclusion criteria: aged 65 to 75 years; residents of greater Vancouver; osteoporotic (based on BMD). Exclusion criteria:< 5 years post menopause; weighed > 130% ideal body weight; other contraindications to exercising; already doing > eight hours /week moderate to hard exercise; planning to be out of city > four weeks during 20 week programme.	a. Exercise class (Osteofit) for 40 minutes, two x per week, for 20 weeks in community centres. Classes of 12 per instructor. Eight to 16 strengthening and stretching exercises using Theraband elastic bands and small free weights. Bimonthly social seminar. b. Control: usual routine activities and bimonthly social seminar separate from intervention group.	Length of follow-up 20 weeks (duration of intervention). Losses: 13 of 93 (14%). Outcomes Falls recorded in falls calendars returned monthly. 1. Number of falls. 2. Static and dynamic balance. 3. Quadriceps strength. Results Report no difference between groups in the number of people falling. No summary statistic for falls reported and insufficient data presented to calculate one.
Cornillon et al., 2002	Randomized controlled trial. Randomized by random number tables. Intention to treat analysis possible.	Setting: community, St Étienne, France. N=303. Subjects: community dwelling and independent in ADL (83% female).	a. Information on fall risk, and balance and sensory training in groups of 10-16. One session per week for eight weeks. Session started with foot and ankle warm-up (walking on tip toe and on heals etc.), walking following verbal orders, walking bare foot on different surfaces, standing on one leg with eyes	Follow-up 12 months. Falls and fall related injuries recorded on six monthly falls calendars. Losses: five of 303 (1.7%). Outcomes 1. Number of participants falling.

		Age: mean 71 years. Inclusion criteria: >65 years old; living at home; ADL independent; consented. Exclusion criteria: cognitively impaired (MMSE <20); obvious disorder of walking or balance.	open and shut, practicing getting up from the floor. b. Control.	2. Mean number of falls (no standard deviation). 3. Mean number of medical care falls (no standard deviation). Results Exercise/physical therapy alone vs control community dwelling untargeted, number of participants falling N=39/148 vs 48/153 RR 0.84 [0.59, 1.20].
Day et al., 2002	Randomized controlled trial. Factorial design. Randomized by 'adaptive biased coin' technique, to ensure balanced group numbers (computer generated by an independent third party by telephone). Intention to treat analysis.	Setting: community, Melbourne, Australia. N=1107. Sample: community dwelling men and women identified from electoral roll (59.8% female). Age: 76.1 ± 5.0. Inclusion criteria: living in own home or apartment or leasing similar accommodation and able to make modifications; aged 70 and over. Exclusion criteria: if not expected to remain in area for two years (except for short absences); had participated in regular to moderate physical activity with a balance component in previous two months; unable to walk 10-20 m without rest or help or having angina; had severe respiratory or cardiac disease; had a psychiatric illness prohibiting participation; had dysphasia; had recent major home modifications; had an education and language adjusted score >4 on the short portable mental status questionnaire; or did not have approval of their general practitioner.	a. Exercise: weekly class of one hour for 15 weeks plus daily home exercises. Designed by physiotherapist to improve flexibility, leg strength and balance - or less demanding routine depending on subject's capability. b. Home hazard management: hazards removed or modified by participants or City of Whitehorse's home maintenance programme. Staff visited home, provided quote for work, including free labour and materials up to $A 100. c. Vision improvement: assessed at baseline using dual visual acuity chart. Referred to usual eye care provider, general practitioner or local optometrist if not already receiving treatment for identified impairment. d. a+b e. a+c f. c+b g. a+b+c h. No intervention. Received brochure on eye care for over 40 year-olds.	Length of follow-up 18 months. Falls reported using monthly postcard to record daily falls. Telephone follow-up if calendar not returned within five working days of the end of each month, or reporting a fall. Losses: 17 of 1,107 (1.5%). Outcomes 1. Time to first fall. 2. Number of fallers. Results Exercise/physical therapy alone vs control community dwelling untargeted, number of participants falling n=76/135 vs n=87/137 RR 0.89 [0.73, 1.08]. Home safety intervention alone vs control, fallers and non-fallers prior to year of randomisation number of participants falling, n=78/136 vs 87/137 RR 0.90 [0.74, 1.10]. Vision assessment and referral vs control, number of participants falling, n=84/139 vs 87/137 RR 0.95 [0.79, 1.14]. Exercise visual correction and home safety intervention (community dwelling). Number of participants falling 1. Exercise, visual correction and home safety n= 65/135 vs control n=87/137 RR 0.76 [0.61, 0.94]. 2. Exercise and visual correction n=66/136 vs control n=87/137 RR 0.76 [0.62, 0.95]. 3. Exercise and home safety intervention n=72/135 vs control n=87/137 RR 0.84 [0.69, 1.03].

Schnelle et al., 2002	Randomized controlled trial. Randomized within nursing homes by 'computerized programs'. Intention to treat not possible.	Setting: nursing homes, California, USA. N=190 (85% female). Sample: residents of four nursing homes. Age: mean (SD) intervention group 87.3 (8.0) years, controls 88.6 (6.7) years. Inclusion criteria: incontinence of urine, able to follow a simple one-step instruction. Exclusion criteria: catheterised, on Medicare Part A reimbursement for post-acute skilled care or terminal illness.	a. FIT intervention (low intensity, functionally oriented exercise and incontinence care) provided every two hours from 8.00 am and 4.00 pm for five days a week, for eight months (see notes for further details). b. Controls: usual care.	Length of follow-up eight months. Falls identified from patient records weekly. Losses: 18 of 190 (9%). <u>Outcomes</u> 1. Number of participants falling. 2. Number of falls. 3. Number of participants sustaining falls with skin injury. 4. Number of participants sustaining a fracture. 5. Number of participants sustaining other fall related injuries. 6. Number of fall related skin injuries. 7. Number of fall related fractures. 8. Number of fall related other injuries. 9. Number of falls per 1000 resident weeks. 10. Number of fall related skin injuries per 1000 resident weeks. 11. Number of fall related fractures per 1,000 resident weeks. 12. Number of other fall related injuries per 1000 resident weeks. <u>Results</u> Exercise plus incontinence management vs control. 1. Number of participants falling, n=17/92 vs n=29/98 RR 0.62 [0.37, 1.06]. 2. Number sustaining fracture fall, n=4/92 vs 1/98 RR 4.26 [0.49, 37.42] 3. Number sustaining injury fall, n=8/92 vs n=11/98 RR 0.77 [0.33, 1.84].
Becker et al., 2003	Randomized controlled trial. Cluster randomized by city government official using sealed envelopes. Intention to treat analysis.	Setting: nursing homes, Germany. N=981. Sample: men and women requiring long-term care in six nursing homes. Age: intervention group 83.5 ± 7.5, control group 84.3 ± 6.9 years. Inclusion criteria: all levels of mobility and cognitive status included. Exclusion criteria: if admitted for post-hospital care, geriatric rehabilitation or palliative care.	Staff training (60 minute course and written information on falls and fall prevention) and monthly feedback (fallers, fall rates, severe injuries). Could discuss problems with study nurse in person or by telephone; environmental adaptations (76 items e.g. lighting, chair and bed heights, floor surfaces, clutter, grab bars for toilets and bathrooms, proper use of walking aids). Hip protectors (safety pants or Safehip, patients' choice) offered to residents who could stand with or without assistance or who occasionally tried to rise from a chair unattended, five protectors per subject, to be worn from arising until going to bed. In addition, residents could choose any combination of the following, for any length of time: written information on fall	Length of follow-up 365 days from a specified date. Losses: none reported. <u>Outcomes</u> Falls and fall sheets completed daily by nursing staff and supervised regularly by study nurse. 1. Number of participants falling. 2. Number with two or more falls. 3. Fall rate per 1,000 person years. 4. Time to first fall. 5. Number of hip fractures. 6. Number of non-hip fractures.

			prevention; personal fall consultation if not bed or chair bound introducing idea of two months exercise and use of hip protectors; group exercise programme (balance and progressive resistance exercises using ankle weights and dumbbells, 75 minutes two x per week).	Results Cluster N=6 =981 participants. Multifaceted intervention vs control. Number of fallers RR 0.75 [0.57, 0.98]. Incidence density rate of falls per 1,000 resident years RR 0.55 [0.41, 0.73] (trialists' analysis).
Latham et al., 2003	Randomized controlled trial. Factorial design. Stratified block randomization; six per block. Randomized to one of tour treatment arms in block using a computerised central randomization scheme. Biostatistician generated the randomization sequence. Intention to treat analysis.	Setting: five hospitals in Auckland, New Zealand and Sydney, Australia. N=243. Subjects: frail older people recently discharged from hospital. Age: mean 79 years. Inclusion criteria: considered frail (one or more health problems e.g. dependency in an ADL, prolonged bed rest, impaired mobility, or a recent fall); no clear indication or contraindication to either of the study treatments. Exclusion criteria: poor prognosis and unlikely to survive six months; severe cognitive impairment; physical limitations that would limit adherence to exercise programme; instable cardiac status; large ulcers around ankles that would preclude use of ankle weights; living outside hospitals' geographical zone; not fluent in English.	a. Exercise: quadriceps exercises using adjustable ankle cuff weights three x per week for 10 weeks. First two sessions in hospital, remainder at home. Monitored weekly by physiotherapist: alternating home visit with telephone calls. b. Exercise control: frequency matched telephone calls and home visits from research physical therapist including general enquiry about recovery, general advice on problems, support. c. Vitamin D: single oral dose of six 1.25 mg calciferol (300,000 IU). d. Vitamin D control: placebo tablets.	Follow-up six months. Falls recorded in fall diary with weekly reminders for first 10 weeks. Nurses examined fall diaries and sought further details about each fall at three and six month visits. Reminder phone call between visits. Losses: 43 of 243 (17%). Outcomes 1. Number of participants falling. 2. Number of falls. 3. Fall rate in person years. 4. Time to first fall. 5. Adverse events. Also measured but not considered for this review, self assessed health (physical component score of SF36), Barthel index, falls self efficacy scale, Adelaide activities profile, quadriceps strength, timed walking test, timed up & go test, Berg balance test. Results Exercise/physical therapy alone vs control, community dwelling (strength training)-individually targeted, 1. Number of participants falling, n=60/112 vs n=64/110 RR 0.92 [0.73, 1.16]. 2. Number sustaining muscoskeletal injury during study, n=18/112 vs n=5/110 RR 3.54 [1.36, 9.19]. Vitamin vs control, community dwelling targeted, number of participants falling, n=64/121 vs n=60/114 RR 1.00 [0.79, 1.28].
Jessup et al., 2003	Randomized controlled trial. Method of randomization - parallel design, random number table designed by Burns and Grove.	N = 18 Age: mean (SD) 69.2 (3.5). Sex: female. Setting: USA Inclusion: healthy women not taking hormone or osteoporosis medication,	Exercise group (MULTIPLE): Strength exercises began with 8 to 10 repetitions at 50% of pre-test 1RM score on progressed to 75%. Load-bearing walking, stair-climbing and balance -training exercises, wearing weighted vests after 2 weeks. Balance-training exercises, in walking.	The EG had significant improvements in bone density of the femoral neck and balance and a significant weight loss (P < 0.05). There were no changes in self-efficacy in either group.

	Assessors blinded to randomization but aware of which group participants were allocated to. Losses: 2 of 18.	or done so in the last 12 months, no regular exercise in the last 12 months. Exclusion: medical history or physical examination revealing cardiac or pulmonary, endocrine, neuromuscular or orthopaedic conditions or dextral results indicating contra indication, visual acuity test less than 20/50, mini mental test less than 20, inability to retain Romberg stance for 20 seconds without losing balance, alcohol or drug abuse, smokers, psychiatric conditions.	Control group: usual activities of daily living. Duration and intensity: 3 sessions (60 - 90 min) per week for 32 weeks Supervisor: research assistant and co investigator Supervision: group Setting: gym Outcomes: Body sway (cm)	
Islam et al., 2004	Randomized controlled trial. Method of randomization not known. Blinding not known. Losses: 4 prior to testing	N = 43 Age: 69 - 89 years. Sex: 20 male, 19 female. Setting: Japan. Inclusion: healthy. Exclusion: taking medication, signs or symptoms of diagnosed disease.	Exercise group (GBFT): balance exercises designed to challenge the visual (e.g. opened /closed eyes), vestibular (e.g. move head), somatosensory (e.g. stand on foam) and muscular (e.g. standing on one leg, bending body in different directions) systems. Exercises were initially performed while standing on the floor (first 4 weeks) and then progressed to standing. Control group: usual activity. Duration and intensity: 2 sessions per week for 60 minutes for 12 weeks. Supervisor: fitness instructor Supervision: individual Setting: gym Outcomes: Maximum excursion of LOS (forward, backward, right, left).	After 12 weeks of training, the TR demonstrated significant improvements in static balance (82%); EPE backward (72%), right (32%), and left (33%); MXE backward (74%), right (31%), and left (18%); and lower body muscle strength (20%) with no significant changes in CN.
Nelson et al., 2004	Randomized controlled trial. Stratified block randomization by gender and age (70 - 79, 80 plus) Assessors blinded. Losses: 4 of 72.	N = 72 Age: over 70 years Sex: 27 female Setting: USA Inclusion: > 70 exercising no more than 1 day/week community dwelling must have 2 functional limitations and score 10 or less on EPESE. Exclusion: Unstable cardiovascular disease, psychiatric disorders, neurological or muscular diseases, terminal illness, cognitive impairment.	Exercise group (MULTIPLE): balance and strength using free weights working at 7/8 on a 10 point Borg Scale, tandem walks, running etc, plus 120 minutes physical activity per week . Control group: attention via nutritional education booklet. Duration and intensity: exercise programme - 3 times a week for 6 months plus 120 minutes physical activity per week. Supervisor: exercise physiologist. Supervision: exercise group - individual self paced, 6 home visits in the 1st month and then monthly, attention control - 2 home visits in 1st month and then monthly. Setting: home. Outcomes: Tandem walk (over 20 feet) (s). One legged stance (max 30 s).	70 participants (97%) completed the 6-month trial. Compliance with study interventions within each group ranged from 75% in controls to 82% in exercisers. PPT increased by 6.1 ± 13.4% in exercisers and decreased by 2.8 ± 13.6% in controls (p =.02). EPESE improved by 26.2 ± 37.5% in exercisers and decreased by 1.2 ± 22.1% in controls (p =.001). Dynamic balance improved by 33.8 ± 14.4% in exercisers versus 11.5 ± 23.7% in controls (p =.0002). There were no differences between groups in the change in strength, gait speed, or cardiovascular endurance.

			Maximum gait speed (over 2 m).	
Seynnes et al., 2004	Randomized controlled trial. Single-blinded, randomized, placebo-controlled trial.	N = 27 (22 followed-up), percentage of men not reported, mean age: 82 ± 6 years. Frail older residents of public nursing homes. Inclusion: ≥70 years, ambulatory = could walk ≥20 m without assistance of another person and able to understand simple instructions.	Intervention: high-intensity (80% 1RM) strength training vs low intensity (40% 1RM) strength training 3 x/wk for 10 wk. Comparison: placebo control (empty ankle cuffs) 3 x/wk for 10 wk. Outcome measures: KE maximal strength, KE endurance, and functional performance as assessed by 6-minute walking, chair-rising, and stair-climbing tests, and by self-reported disability.	KE strength and endurance, stair-climbing power, and chair-rising time improved significantly in the HI and LI groups compared with the PC group. Six-minute walking distance improved significantly in the HI group but not in the LI group compared with the PC group. Changes observed in HI were significantly different from those observed in the LI group for KE strength and endurance and the 6-minute walking test, with a trend in the same direction for chair-rising and stair-climbing. Changes in strength were significantly related to changes in functional outcomes, explaining 37% to 61% of the variance.
Suzuki et al., 2004	Randomized controlled trial. Randomization by random number tables. Assessors blinded. Losses: 8 of 52. Intention to treat analysis.	N=52 Sex: female Age: 77.31 ± 3.4 exercise, 78.64 ± 4.39 control. Setting: Japan Inclusion: 73-90 years, participants in longitudinal study on aging. Exclusion: marked decline in ADL, hemiplegia, missing baseline data.	Exercise group (MULTIPLE): exercise centred falls prevention programme with home based exercise aimed at enhancing muscle strength, balance and gait. Included resistance exercise and Tai Chi. Control group: usual activity and a pamphlet and advice on falls prevention. Duration and intensity: 1 exercise session every 2 weeks for 6 months (10 hours). Supervisor: not stated. Supervision: group and self. Setting: community Outcomes: Single legged stance (s), eyes open (max 1 min), eyes closed (max 30 sec) (s), walking speed (over 11 m) (m/s), tandem walk (over 2.5m) (steps).	The average rate of attendance at exercise class was 75.3% (range, 64% to 86%). Participants showed significant improvements in tandem walk and functional reach after the intervention program, with enhanced self confidence. At the 8-month follow-up, the proportion of women with falls was 13.6% (3/22) in the intervention group and 40.9% (9/22) in the control group. At 20 months, the proportion remained unchanged, at 13.6% in the intervention group, but had increased to 54.5% (12/22) in the control group, which showed a statistically significant difference between the two groups (Fisher's exact test; P = 0.0097). The total number of falls during the 20-month follow-up period was 6 in the intervention group and 17 in the control group.
Boshuizen et al., 2005	Randomized controlled trial. Method of randomization not known. Assessors blinded. Losses: 23 of 72 from 3 arms.	N = 33 completers in two arms Age: 80.0 ± 6.7 exercise group, 77.2 ± 6.5 control group. Sex: high guidance group - all female, medium guidance group - 2 male, control group 2 male. Setting: Netherlands. Inclusion: difficulty getting up from	Exercise group (STRENGTH) (n = 16): strengthening exercises of lower limbs with theraband and increasing resistance in sitting and standing. Control group (n = 17): usual activity. Duration and intensity: 10 weeks of 2 x 1hour supervised classes per week and 1 self supervised home session. Supervisor: physical therapist for exercise groups. Supervision: group exercise classes for exercise groups and	Maximal isometric knee strength increased more in HG than in C (p = .03) and with increasing guidance (p = .03). The effect was mainly the result of participants with low initial strength. Walking speed increased more for HG than for C (p = .02) and than for MG (p = .06). No statistically significant improvements were seen on other functional tests.

		chair. Exclusion: maximum knee extensor torque over 87.5 Nm, self reported disease adversely affected by exercise.	self home exercises. Setting: community. Outcomes: 20 metre walk test (s). TUG (s). Tandem stance (s).	
Lord et al., 2005	RCT. Randomized in matched blocks using concealed allocation, drawing lots. Assessors blinded. Losses: 144 of 620 Intention to treat analysis.	N = 620 Age: 75 - 98, 80.4 ± 4.5. Sex: females 409, males 211. Setting: Australia Inclusion: 75 years plus, community living. Exclusion: minimal English language skills, blind, Parkinson, short portable mini mental test less than 7, and not considered risk of falling.	Exercise group (MULTIPLE): based on falls risk profile, individualised exercises aimed at improving strength, and balance and or vision if a problem, peripheral warm up, conditioning, strength, flexibility, coordination and balance. Minimal intervention group: instruction sheets for home exercise. Control group: usual activity Duration and intensity: sessions 1hr x 2 week for 12 months (only data for initial 6 months reported) Supervisor: trained supervisor Supervision: group Setting: community Outcomes: Postural sway on floor and foam eyes open and eyes closed (mm) (Lord sway meter) Co-ordinated stability test (errors).	At the 6-month follow-up, PPA falls risk scores were significantly lower in the EIG than in the CG. EIG subjects assigned to the extensive exercise intervention group showed significant improvements in tests of knee flexion strength and sit-to-stand times but no improvements in balance. EIG subjects assigned to the extensive visual intervention group showed significant improvements in tests of visual acuity and contrast sensitivity. The rate of falls and injurious falls within the trial period were similar in the three groups.
Faber et al., 2006	Randomized controlled trial, with 52-week follow-up.	N = 278 (208 followed up), 21% men, mean age: 85 ± 6 years. Residents of 15 LTC facilities (frail and pre-frail), frail = meeting at least 3 of 5 frailty criteria: (i) BMI <18.5; (ii) SF-36 physical function <75; (iii) SF-36 vitality score <55; (iv) walking speed below sex and height corrected cut-off scores; and (v) physical activity <65 minutes/ day.	Intervention: 'functional walking' (balance, mobility, and transfer training) or 'in balance' derived from principles of Tai Chi, both moderate intensity, 1 x/wk for 4 wk, followed by 2 x/wk for 16 wk, 60 min for 20 wk. Comparison: no intervention. Outcomes: Falls, Performance Oriented Mobility Assessment (POMA), physical performance score, and the Groningen Activity Restriction Scale (GARS) (measuring self-reported disability).	Fall incidence rate was higher in the FW group (3.3 falls/y) compared with the IB (2.4 falls/y) and control (2.5 falls/y) groups, but this difference was not statistically significant. The risk of becoming a faller in the exercise groups increased significantly in the subgroup of participants who were classified as being frail (hazard ratio [HR] = 2.95; 95% confidence interval [CI], 1.64-5.32). For participants who were classified as being pre-frail, the risk of becoming a faller decreased; this effect became significant after 11 weeks of training (HR = .39; 95% CI, .18-.88). Participants in both exercise groups showed a small, but significant improvement in their POMA and physical performance scores. In the FW group, this held true for the GARS score as well. Post hoc analyses revealed that only the pre-frail participants improved their POMA and physical performance

				scores.
Miller et al., 2006	Randomized controlled trial with 12-week masked outcome assessment.	N = 100 (93 followed-up), 21% men, mean age: 84 years (95% CI: 82, 85). Nutritionally at-risk patients from orthopaedic ward. Inclusion: ≥70 years, hospitalized following a fall-related lower-limb fracture between Sep 2000 and Oct 2002, malnourished, (<25th percentile for mid-arm circumference of older Australians – 27.0 cm and 26.3 cm for males and females, respectively).	Intervention: resistance training of the using elastic bands, 3 x/wk, 20–30 min for 12 wk. Comparison: home visits (discussions about benefits of regular exercise and nutrient-dense meals) 3 ×/wk for wk 1–6 and 1 x/wk for wk 7–12. Outcomes: Weight change, quadriceps strength, gait speed, quality of life and health care utilization at completion of the 12-week intervention.	At 12 weeks, all groups lost weight: nutrition -6.2% (-8.4, -4.0); resistance training -6.3% (-8.3, -4.3); nutrition and resistance training -4.7% (-7.4, -2.0); attention control -5.2% (-9.0, -1.5). Those receiving resistance training alone lost more weight than those receiving the combined treatment (P= 0.029). Significant weight loss was prevented if supplement was consumed for at least 35 days. Groups were no different at 12 weeks for any other outcome.
Wolf et al., 2006	Randomized controlled trial. Dropouts: 69 of 311. Intention to treat analysis.	N = 311 (286 followed-up), 6% men, mean age 81 ± 6 years. Inclusion: older adults from congregate living facilities 'transitionally frail', who had fallen ≥1 time in the last year. 10 matched pairs of facilities randomized.	Intervention: intense Tai-Chi exercise 2 x/wk 60–90 min supervised and 4–5 d/wk 10–30 min at home for 48 wk. Comparison: 'wellness control': lectures 1 x/wk, 60 min for 48 wk. Outcomes: Physical performance (freely chosen gait speed, reach, chair-rises, 3608 turn, picking up an object from the floor, and single limb support) and hemodynamic outcomes (heart rate and blood pressure) were obtained at baseline and after 4, 8, and 12 months.	Mean percent change (baseline to 1 year) for gait speed increased similarly in both cohorts (TC: 9.1% and WE: 8.2%; p ¼ .78). However, time to complete three chair-rises decreased 12.3% for TC and increased 13.7% for WE (p ¼ .006). Baseline to 1 year mean percent change decreased among TC and increased within WE cohorts for: body mass index (–2.3% vs 1.8%; p , .0001), systolic blood pressure (–3.4% vs 1.7%; p¼.02), and resting heart rate (–5.9% vs 4.6%; p , .0001).
Zhang et al., 2006	Randomized controlled trial. Randomized by tossing a coin after pairing by sex, falls and exercise habits. Blinding not known. Losses: 2 of 49.	N = 49. Age: mean (SD) 70.2 (3.6) Tai Chi, 70.6 (4.9) control. Sex: 25 male, 24 female. Setting: Japan. Inclusion: Community dwelling, scoring 20 -25 seconds on one legged stance time.	Exercise group (3D): Tai Chi simplified form of 24 forms plus 11 easy forms at home. Control group - usual activities. Duration and intensity: 1 hour, 7 times per week for 8 weeks. Supervisor: Tai Chi instructor. Supervision: group and self. Setting: community in park and home. Outcomes: One legged stance eyes open (max 60 s). Walking speed (10 metres).	The Tai Chi Chuan group showed significant improvements in balance and flexibility, and a reduced fear of falling, when compared with the control group after the intervention. However, walking speed did not change significantly.
Sullivan et al., 2007	Double-blind, randomized, controlled intervention using a two-by-two factorial design and conducted between 1999 and 2001.	N = 29 randomized (24 followed-up), 83% men, mean age: 79 ± 7 years. Patients from a geriatric evaluation and management unit or clinic. Inclusion: recent illness-induced functional decline, aged ≥65 years, capable of giving informed consent.	Intervention: high-intensity progressive resistance muscle strength training (80% 1RM) for 12 wk. Comparison: low resistance muscle toning exercise (20% of 1RM) for 12 wk. Outcomes: Change in muscle strength, mid-thigh muscle area, and aggregate functional performance score as assessed using analysis of covariance.	Five subjects withdrew from the study before its completion. Based on intent-to-treat analyses, subjects who received high-intensity PRMST and placebo experienced the greatest strength gains. The addition of MA was associated with worse outcomes than with high-intensity exercise training alone, especially with regard to the leg

				exercises. Post hoc analysis demonstrated that subjects who received high-intensity PRMST and placebo experienced significantly greater percentage increases in leg strength than subjects in either of the MA treatment groups (P<.05 for each comparison). There was also a significant negative effect of MA on physical function. In general, subjects who received MA experienced a deterioration in aggregate physical function scores, whereas the remaining subjects improved (-0.80+/-0.40 vs 0.48+/-0.41, P=.04). There was not a significant interaction between exercise and MA for any outcome.
Littbrand et al., 2009	Randomized controlled trial. Nine residential care facilities. Intention to treat analysis.	N = 191 older people dependent in ADLs and with a Mini-Mental State Examination score of 10 or greater. One hundred (52.4%) of the participants had dementia.	Intervention: high-intensity functional weight bearing exercise program consisting of 29 sessions over 3 months, to improve the participants' lower limb strength, balance, and gait by exercising in functional weight-bearing positions. The exercises mimicked movements used in everyday tasks, for example, standing up from a sitting position, step-ups, squats, turning trunk and head while standing, and walking over obstacles. Control: included activities while sitting (e.g., watching a film, reading, singing, and conversation) for this study. Outcomes: The Barthel ADL Index; follow-up at 3 months (directly after the intervention) and 6 months.	There were no statistically significant differences between the groups regarding overall ADL performance. Analyses for each item revealed that a smaller proportion of participants in the exercise group had deteriorated in indoor mobility at 3 months (exercise 3.5% vs control 16.0%, P=.01) and 6 months (7.7% vs 19.8%, P=.03). For people with dementia, there was a significant difference in overall ADL performance in favour of the exercise group at 3 months (mean difference 1.1, P=.03) but not at 6 months.

Universitat Ramon Llull

Aquesta Tesi Doctoral ha estat defensada el dia ____ d __________________ de 2010 a la Facultat de Psicologia, Ciències de l'Educació i de l'Esport Blanquerna de la Universitat Ramon Llull, davant el Tribunal format pels Doctors sotasignants, havent obtingut la qualificació:

President/a

____

Vocal

____

Secretari/ària

____

Doctoranda

MARIA GINÉ GARRIGA

C. Claravall, 1-3
08022 Barcelona
Tel. 936 022 200
Fax 936 022 249
E-mail: urlsc@sec.url.es
www.url.es