FIELD TESTING AS AN ALTERNATIVE TO ISOKINETIC TESTING OF THE ANKLE

By
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Submitted to the Faculty of Graduate Studies
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for the Degree of

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LIST OF ABBREVIATIONS

PT - peak torque

RTD - rate of force development

PS - passive stiffness

PF - plantar flexion

DF - dorsiflexion

pf0^0 - isometric plantar flexion in the neutral position of 0^0

pf20^0- isometric plantarflexion performed at 20^0 of plantarflexion

df0^0 - isometric dorsiflexion in the neutral position of 0^0

df20^0- isometric dorsiflexion performed at 20^0 of plantarflexion

ABSTRACT

Although strength, rate of torque development and stiffness of the ankle can be measured using isokinetic dynamometry, it is possible that simple field tests can provide similar information. This information may give insight into the deterioration of mobility that occurs with aging. To test this, 30 younger (30 to 50 years) and 27 older (≥70 years) healthy adult volunteers completed a battery of field tests and isokinetic tests. Sixteen males and 14 females comprised the younger group and 14 males and 13 females the older group. Field tests assessed tasks of foot tapping, balance, grip strength, chair stand, chair sit-and-reach, back scratch, 8-foot up and go, and reaction time. Isokinetic tests used a Biodex System 3 Professional isokinetic dynamometer to measure maximal isometric strength (PT), rate of torque development (RTD) and passive stiffness (PS) of both the plantar and dorsiflexors of the right ankle. Correlation and multiple regression techniques were used to analyse the relationships between field and isokinetic tests. This analysis was performed using results for the entire sample of 57 subjects, and again using only the results of the 27 older subjects. Age and sex differences were investigated using ANOVA.

Grip strength was the best indicator of PT and RTD for both plantar flexion (PF) and dorsilexion (DF) when results for the entire sample were analysed. This was also the case for the older group apart from PF RTD where the chair stand and

8-foot up and go tests proved to be the best. There was a significant correlation between the back scratch test and PS for the total sample, but not for the older group. An age effect was present only for DF in the 0^0 position for both PT and RTD. There was a sex effect in all isokinetic tests apart from RTD for PF in the 0^0 position.

Results from this study suggest that the grip strength, chair stand and 8-foot up and go tests can be used together to provide a good indication of an older individual's ankle strength and RTD. This may prove useful to future aging research by providing a simple means of assessing changes in ankle function in order to investigate its influence on the deterioration of functional ability of older adults.

INTRODUCTION

Research related to aging has been expanding in recent years with particular interest being shown in the quality of life of older adults. This is strongly tied to the functional capability of these individuals and their consequent ability to live independently. In Canada, one in four seniors are reported to suffer a long term health problem that limits their activities (Division of Aging and Seniors, 2002). Informal home care, provided mostly by friends and family members, is common amongst Canadian seniors with a reported 5 out of 6 receiving assistance in 1996 (Division of Aging and Seniors, 2002). Difficultly with climbing stairs, walking short distances, or even rising from a chair or bed are some of the everyday tasks that are typically affected as age increases and can result in older adults becoming dependent on informal or institutionalized care (Shephard, 1997). Although we all hope to live a healthy and active life to the end, the average individual will spend a significant number of their final years with a partial or total disability making them dependent on others in everyday living (Shephard, 1997).

Changes in the functioning of the ankle may be particularly relevant to the mobility of this population and so deserves closer study. The movement of the ankle joint is central to the activities of standing and walking (Shih et al., 1993). Therefore, age-related changes in this joint's ability to perform its regular movements, or the quality of these movements, would be expected to impact an individual's mobility and consequent functional independence. Understanding the mechanisms behind these changes may enable us to find an appropriate intervention which can reduce functional degeneration in the future. Ankle strength, stiffness and rate of torque development are three such areas that may provide some enlightening information if studied more extensively.

Strength

It has been well established that strength decreases with age (Mazzeo et al., 1998; Porter et al., 1995; Shephard, 1997). Although there are some discrepancies regarding the precise turning points, the majority of research suggests that voluntary strength increases until young adulthood, somewhat plateaus during the middle years, and then begins to noticeably decline after approximately 60 years of age with accelerated loss occurring in later years (Mazzeo et al., 1998; Porter et al., 1995). Losses in strength appear to be more noticeable in women than men (Mazzeo et al., 1998; Porter et al., 1995; Shephard, 1997).

It is thought that the effects of aging on muscular strength are similar between all muscles (Porter et al., 1995). From this we can assume that the dorsiflexors and plantar flexors of the ankle decrease in strength as a result of aging to a similar degree as do other muscles in the body. In support of this, Vandervoort and Hayes (1989) found young women (20-30 years) had greater isometric plantar flexor strength than elderly women (73-91 years). A further study by Vandervoort et al. (1992a) found an age related loss of dorsiflexor strength in a group of adults ranging from 55 to 85 years. Men and women had similar relative losses after age 60 although men showed the greatest absolute strength loss. Men demonstrated greater strength than women at all ages.

Thelen et al. (1996) found older adults (mean age 72 years) had lower plantarflexor and dorsiflexor isometric strength when compared to younger men and women (mean age 23 years). Absolute strength loss was greatest in the plantar flexors. In a sample of men and women aged 20 to 100, Vandervoort and McComas (1986) also found plantarflexor and dorsiflexor isometric strength decreased as age increased with significant strength declines beginning after age 60. Although absolute losses were greater for plantar flexors, relative losses were similar for plantar and dorsiflexors. In contrast to these studies, Horstmann et al. (1999) found no age-dependent loss of plantarflexor and dorsiflexor isometric strength in men aged between 20 and 60 years. No explanation for these conflicting results was given apart from possible differences in methodology.

Older adults have demonstrated that they are capable of fully activating muscle fibres (Vandervoort and McComas, 1986; Kent-Braun and Ng, 1999). Consequently, the decrease in strength is generally attributed to the decrease in muscle mass which also occurs with aging (Mazzeo et al., 1998; Porter et al., 1995). Muscle atrophy results from a decrease in size as well as the total number of muscle fibres with type 2 fibres being most affected (Porter et al., 1995; Shephard, 1997; Mazzeo et al., 1998). There is also a reduction in the number of motor neurons and an associated increase in the size of those motor units that remain (Porter et al., 1995).

Wolfson et al. (1995) has linked decreased ankle strength to elderly people with a history of falling. Authors studied the effects of strength, balance and gait on the occurrence of falls in nursing home residents and found those with a history of falls had less than one half the lower limb strength of non-fallers. Differences in ankle strength were greater than those in knee strength while differences in dorsiflexion were greater than the differences in plantar flexion. Fallers also had a lower gait velocity and lost their balance more easily. It was suggested that there is a strength threshold below which gait and balance are likely to be affected.

Decreased ankle strength has also been associated with a reduction in walking speed which typically occurs with aging (Alexander,1996). Slower gait has been attributed to shortened stride length which becomes particularly noticeable in the 6th decade (Alexander,1996). This is partially due to a decrease in pushoff power (Winter et al., 1990) along with an attempt to increase stability (Maki, 1997). Slower walking speed may, in turn, be a risk factor for pedestrian traffic accidents involving older adults. Older adults (particularly over the age of 65 years) appear to have a disproportionally high number of deaths as a result of pedestrian traffic accidents as compared to younger adults (Allard, 1982; Harruff,1998; Sklar et al., 1989). Walking velocity is particularly important for safely crossing traffic intersections. In fact, Hoxie and Rubinstein (1994) found that 27% of older adults were unable to cross a traffic intersection before the lights changed to allow traffic to pass, making these people more vulnerable to oncoming traffic.

Rate of Torque Development

The term 'rate of torque development' is used to describe the speed at which force can be developed within a muscle or muscle group. In vivo, the forces studied are about a joint so the force is technically a torque, although the term 'rate of force development' is also used and can be found in the literature.

It has been suggested that the rate at which a force can be developed is more relevant than maximal strength when evaluating dynamic movement capabilities (Wilson and Murphy,1996). In support of this, Bassey et al. (1992) found leg extensor power in older adults was significantly correlated to the everyday movements of stair climbing, rising from a chair and walking. Similarly, Winter et al. (1990) found a decrease in pushoff power of the ankle plantar flexors of older adults resulted in an altered walking pattern. Authors also recorded a decrease in dynamic balance. Izquierdo et al. (1999) suggests this is a result of reduced rates of force development which may impair the ability of older adults to make timely postural adjustments.

Testing of RTD can involve single or multi-joint protocols requiring either isometric or dynamic contractions. Contractions may be performed either maximally or submaximally and may be voluntary or involuntary. With the number of potential variables involved with testing RTD, comparing research outcomes can be confusing. To add to the confusion, a wide variety of measurement techniques are used to quantify RTD.

Wilson and Murphy (1996) state that maximal rate of force development is typically measured as the greatest slope of the force time curve. However, the authors go on to point out that there is a great deal of variation in the section of the curve selected for analysis. For example, the RTD may be measured:

- over a defined time interval e.g. steepest gradient over a given 50 msec period (Lamoureux et al., 2001)
- over the time taken to reach a specified force, e.g., time to 500N (Hakkinen et al., 1985)
- over the time taken to reach a relative force, e.g., 50% of maximal (Thelen et al., 1996)

A close look at research on RTD in lower limb reveals there are consistent findings - despite variations in quantification methods. Larsson et al. (1979) found maximal knee extension velocity decreased with age in the quadriceps of males between 11 and 70 years of age. The decrease followed a similar pattern to age related decreases in strength. Lamoureux et al. (2001) found large decreases in RTD in the same muscle group between old (<70 years of age) and older (>70 years of age) adults illustrating loss continues to occur after the 7th decade. Again, this is consistent with the pattern of strength changes with age. Hakkinen and Hakkinen (1991), Izquierdo et al. (1999), and Bassey et al. (1992) have all found that the rate at which the leg extensors develop force decreases with age. All suggest that it is greater than the decrease that occurs in strength.

In research specific to the ankle, older adults have required greater time to reach the same absolute torques as younger adults in both the dorsiflexors (Thelen et al., 1996; Kent-Braun and Ng, 1999) and the plantar flexors (Thelen et al., 1996). However, in both studies, the differences were minimized when torques were normalized to a percentage of maximum torque. Regardless, as Thelen points out, in time-critical situations such as recovering balance, it is the absolute rather than relative measurements that are of greatest importance.

Findings of reduced RTD in voluntary ankle torques with age is supported by research on electrically stimulated twitches of the plantarflexor and dorsiflexor muscles. Davies et al. (1986), Ng and Kent-Braun (1999) and Vandervoort and McComas (1986) have all found slower twitch force production in older adults.

There is no strong evidence to suggest that universal gender differences exist in either voluntary or involuntary contractions.

Theories explaining this decreased RTD with age are related to either changes in muscle fibre types or neural factors. The muscle atrophying consequences of aging, predominantly of the fast twitch fibres, may be the cause of slowing contraction times (Porter et al.,1995). It is also possible that neural factors are responsible. Vandervoort and McComas (1986) and Kent-Braun and Ng (1999), have shown that older adults are capable of fully activating motor pathways to muscles associated with ankle movement. However, Hakkinen and Hakkinen (1991) and Lamoureux et al. (2001) suggest that the rate of neural activity may decrease with age.

Stiffness

The term 'stiffness' is used to describe an object's pliability. At a mechanical level it has been defined as the resistance of a structure to deformation (Gleim and McHugh, 1997). In relation to human movement, stiffness describes the ease with which movement occurs through a range of motion with a higher level of stiffness corresponding to a greater resistance to movement (Gleim and McHugh, 1997).

Total stiffness of a joint is the sum of its passive and active stiffness (Gajdosik., 2001). Active stiffness refers to the active or purposeful resistance to movement which can be imposed by an antagonistic muscle group. In contrast, passive stiffness is a result of the resistance to movement of passive structures (i.e., joint capsule, ligaments, muscle and skin) and so is a measure of the external force needed to move a relaxed limb through a range of movement.

Increased passive stiffness may decrease an individual's active range of motion thus affecting daily activities (Vandervoort et al., 1992b; Gajdosik, 2001). For example, a reduced range of dorsiflexion can affect toe clearance in gait and stair climbing causing tripping and stumbling (Winter et al., 1990). This is not suggesting that passive stiffness is synonymous with range of motion, but rather, that greater strength may be required to move a limb through the same range of motion when the movement is being resisted by stiffer structures. As a result, those individuals who do not possess the required strength will have a decreased active range of motion.

Passive stiffness can also positively influence locomotor activities. The force that resists movement in one direction can contribute to movement in the opposite direction (Gleim and McHugh, 1997). For example, in humans, stiffness of the plantar flexors will resist dorsiflexion but will contribute to the propulsive push-off force in walking (Salsich et al., 2000). It is also possible that increased levels of stiffness are responsible for the maintenance of eccentric force production in the ankles of older adults (Horstmann et al.,1999).

Furthermore, Gleim and McHugh (1997) suggest that higher levels of passive stiffness provide more efficient transfer of forces resulting in more economical walking and running.

Research suggests that changes to passive stiffness in a specific joint are predominantly due to changes in the stiffness of the muscle-tendon unit such as increased amounts of connective tissue (Alnaqueeb et al., 1984). Collagen is a major component of connective tissue and has been correlated with muscle stiffness (Alnaqueeb et al., 1993; Gajdosik, 2001). A higher concentration of collagen generally results in higher levels of passive stiffness.

The structure of the collagen is also significant. Collagen molecules have a tendency to form abnormal cross-links with other molecules creating a less pliable collagen with increased tensile strength and increased stiffness (Buckwater, 1997; Hayflick, 1985; Shephard, 1997). This particularly occurs with aging (Hayflick, 1985; Shephard, 1997).

Deformation of cross-bridge attachments between actin and myosin filaments in muscle has been suggested to contribute to the passive stiffness of muscle (Gajdosik, 2001; Proske and Morgan, 1999). Consequently, greater muscle mass would result in greater passive stiffness due to the increased number of crossbridge attachments. An alternative school of thought suggests that it may be titin - an elastic filament that keeps the thick filaments of muscle centred between the z-lines during contraction - rather than the cross-bridge attachments that is resisting elongation (Wang et al., 1991).

With the above knowledge of connective tissue and muscle filaments, the variability in passive stiffness that occurs between individual muscles and ligaments may be attributed to the following:

Muscle mass Because muscle resists elongation, it follows that an increase in muscle mass will result in an increase in resistance (Wright, 1973; Gajdosik, 2001). This is due to the greater amount of titin (or perhaps, number of cross-bridges) that exist.

Fibre type Slow twitch fibres have been shown to contain larger amounts of collagen as compared to fast twitch fibres (Gillette and Fell, 1996). Therefore, muscles containing a greater proportion of slow twitch fibres will tend to be stiffer (Gleim and McHugh, 1997; Shephard, 1997).

Sex It has been noted that females exhibit less overall passive stiffness than males (Vandervoort et al., 1992a; Vandervoort et al., 1992b). This is not surprising considering the general tendency for females to have less muscle mass than males (McArdle et al., 1996).

Immobilization / disuse Immobilization and disuse can have varying effects on stiffness. One would expect a decrease in passive resistance as a result of immobilization due to muscle atrophy. However, atrophy may be accompanied by an increase in connective tissue (Alnaqueeb et al., 1984) which acts to increase resistance. So, although increases in passive stiffness are most common in immobilization and suspension studies (Gleim and McHugh, 1997), other alternatives are possible.

In reference to the above list, there are a number age-related muscular changes that could potentially affect stiffness levels. With aging comes an increase in intramuscular connective tissue (Rice et al., 1989) and an increase in the collagen content of connective tissue (Alnaqueeb et al., 1984; Rice et al., 1989). The number of collagen cross-links also increases (Shephard, 1997). Furthermore, there is a greater prevalence of slow twitch fibres and a related decrease in muscle cross-sectional area (Porter et al., 1995). Taking this into consideration, it would be reasonable to presume that increased passive stiffness occurs with aging. However, evidence supporting this is not conclusive. Research has provided conflicting results - some studies showing an increase in stiffness with age (Johns and Wright, 1962; Wright, 1973; Alnaqueeb et al., 1984), some a decrease (Gajdosik, 1997), and some have found no significant change (Alnaqueeb et al., 1984; Chesworth and Vandervoort, 1989). It has been suggested that the age-stiffness relationship may be joint specific (Chesworth and Vandervoort, 1989) but this needs further investigation.

As with the general age-related research on stiffness, the research specific to ankle stiffness is full of contradictions. Alnaqueeb et al (1984), Vandervoort et al (1992b), and Porter et al (1996), all reported higher levels of plantarflexor passive stiffness in older subjects whereas Chesworth and Vandervoort (1989) found no significant difference. Gajdosik (1997) found less passive stiffness associated with increased age. Blanpied and Smidt (1993) were unable to draw a definitive conclusion from results of their research.

A decrease in the range of ankle movement with age - specifically the degree of dorsiflexion that can be achieved - has been consistently reported (Gajdosik, 1997; James and Parker, 1989; Salsich et al., 2000, Vandervoort et al.,1992a; Vandervoort et al.,1992b). This is attributed to shortening of the plantarflexor muscles which Gajdosik (1997) suggests is probably due to muscle atrophy and a lack of regularly lengthening these muscles. One might expect short muscles to lead to increased plantarflexor stiffness but, as previously mentioned, this is not necessarily the case. In fact, a number of plantarflexor studies have shown that despite the shortening of this particular muscle group, the slope of the stiffness curve has remained the same indicating no change in stiffness (Chesworth and Vandervoort, 1989; Gillette and Fell, 1996; Salsich et al., 2000). Gajdosik (1997) actually found a decrease in plantarflexor passive stiffness with age in men over the age sixty. This was probably due to a decrease in muscle mass and consequent decrease of structures which resist muscle elongation.

Research regarding plantarflexor composition has found an age-related increase in connective tissue, intramuscular fat and subcutaneous adipose tissue (Rice et al., 1989). However, this does not necessarily indicate an increase in collagen content - the major 'stiffening' agent of connective tissue. In fact, Gajdosik (1997) found his research on age and calf muscle passive stiffness did not support the theory of increasing muscle collagen with aging. In contrast, Alnaqueeb et al. (1984) did find an increase in collagen concentration in the hind limb muscles of older rats although, surprisingly, they did not find an increase in stiffness of the soleus - an important plantar flexor. With conflicting results such as these, it cannot be said with certainty that collagen concentration plays a role in the changes in stiffness of plantar flexors with age.

Overall, evidence supporting an increase in passive stiffness with age is inconclusive. Structural changes that occur in aging muscle and tendon would lead us to suspect an increase, however, the research cannot conclusively support this. It has been suggested that passive stiffness is joint specific. Even so, researchers have been unable to make a conclusion related specifically to the passive stiffness of the plantar flexors of the ankle. In order to make a conclusive statement in regard to passive stiffness, plantar flexors and age, further research is needed.

Assessment Techniques

Strength, rate of torque development and passive resistance can all be accurately measured using isokinetic dynamometry which has been shown to give reliable and valid results when careful subject positioning and protocol selection are carried out (Baltzopoulos and Brodie, 1989; Holmbäck et al., 1999; Porter et al., 1996). However, this method does have drawbacks. Isokinetic dynamometers are expensive and complicated pieces of equipment. Trained technicians are required to performed tests. Consequently, cost and availability of equipment and technicians can be limiting factors in the use of this equipment in research. Furthermore, testing can be time consuming creating large time demands on researchers and their subjects. This may negatively impact the sample size used in research projects thus limiting the generalizability of results.

Field testing is a possible alternative to isokinetic dynamometry. Typically, field tests are simple to administer, require relatively inexpensive equipment, and the equipment required is portable. These attributes reduce the limitations of cost, equipment, and technician availability, enabling testing to be performed on large numbers of subjects.

There are a number of fitness field tests that are influenced by ankle function even though the tests are not designed to specifically evaluate that aspect. For example, although the 8-foot up and go test is used in the Senior Fitness Test as a test of agility and dynamic balance (Rikli and Jones,2001), one would expect those individuals with a fast rate of force development in their plantar flexors to have an advantage over those who do not. Therefore, it would be reasonable to expect the measurements to be related. Consequently, a simple field test could be used as an alternative to isokinetic dynamometry.

It is not uncommon for field tests to be used to predict physical characteristics that could be measured more directly in a laboratory setting. For example, an individual's aerobic fitness is frequently measured by use of a submaximal test which is less expensive and has fewer risks involved (McConnell, 2001). Similarly, skinfolds are a relatively simple field test which can be used to determine the body composition of an individual (Going and Davis, 2001).

With these points in mind, the purpose of this study was to investigate the possibility that field tests can be used in place of isokinetic tests. Data collected was further used to identify differences that may occur between older and younger subjects and between males and females. It was hypothesized that:

1. Selected field tests can be used as an alternative means of assessing passive stiffness of the ankle, isometric strength, and rate of torque development in both the plantar and dorsiflexors of the ankle in older adults;

2. Younger adults would have significantly greater isometric ankle strength, significantly lower ankle passive stiffness and a faster rate of torque development than older adults;

3. Sex differences in strength, passive stiffness and rate of force development would be significant in both the older and younger age groups.

The field tests used in this study were foot tapping, balance, grip strength, chair stand, chair sit-and-reach, back scratch, 8-foot up and go and reaction time. Tests were chosen due to the possible influence that ankle mechanics may have on their results.

METHODS

Subjects

Thirty younger and 27 older adults participated in this study. The younger group ranged in age from 30 to 49 years while the older group ranged from 70 to 85 years. Subjects were volunteers who responded to posters, email bulletins, or word of mouth. There was no payment for participation in this study although all volunteers were given a $10.00 reimbursement for travel expenses. An informed consent form was signed by subjects prior to testing (Appendix B).

This study was approved by the Education/Nursing Research Ethics Board at the University of Manitoba.

Subjects were screened for cardiovascular disease and any musculoskeletal condition that could be exacerbated by test protocols. A Physical Activity Readiness Questionnaire (PAR-Q) screening tool was initially used for this purpose (Appendix C). Those who answered 'yes' to any question on the PAR-Q were further interviewed to establish the extent of their condition. Subjects were excluded from participation in the study if testing was potentially detrimental to their health or if their health could inhibit their performance of maximal tests.

As this study was part of a larger study related to driving performance (see Appendix A), subjects were also required to meet the criteria specific for that study i.e., subjects required a current driver's license and a registered and insured car. They also needed to satisfactorily pass a driver Self-Rating Form (Appendix D).

Testing Sessions

On arrival at the lab, subjects were seated and interviewed on their physical activity habits over the last two months. A physical activity questionnaire was completed by the interviewer recording type, duration, frequency and intensity of physical activities (Appendix E). From this, the subjects' activity level was rated according to the Grimby scale (Grimby, 1986). This is a six level scale based on intensity and duration of weekly physical activity with level one corresponding to hardly any and physical activity and level six corresponding to regular hard exercise. Physical activity did not play a role in the selection or exclusion of subjects for the study.

Following this, the subject's resting blood pressure and heart rate was measured and recorded using an auto-inflate electronic blood pressure monitor (Almedic, Quebec). As a safety precaution, subjects were required to have a systolic blood pressure no higher than 140mmHg and a diastolic blood pressure no higher than 90mmHg in order to proceed with testing. For the same reason, resting heart rate was not to exceed 100 beats per minute (Canadian Society for Exercise Physiology, 1996). Subjects who exceeded these measurements, even on repetition, did not participate in isokinetic testing or in those field tests which required a high level of physical exertion. Height and weight was measured to the nearest 0.5 cm and 0.5 kg using a physician's scale and stadiometer. Once these measurements were recorded, subjects proceeded with field and laboratory testing. All tests were performed by the same tester.

Field Tests

Field tests are presented in the order they were performed. As stretching can decrease stiffness for up to one hour (Gleim and McHugh, 1997), those tests anticipated to be most affected by prior activity were performed first. Consequently, foot tapping, balance and passive stiffness testing were the first three tests performed. In order to do this, isokinetic testing was carried out between the balance and grip strength tests.

Foot tapping The subject was seated with hip and knee angles approximating 90^0. A stable, straight-backed chair with a seat height of approximately 43 cm (17 inches) was used. The chair did not have arm rests. Feet were comfortably spaced and flat on the floor. Subjects were instructed to tap the ball of their right foot as many times as possible in a 10 second period while keeping their heel on the floor. They were instructed to use a full range of motion as opposed to twitch-like movements. The number of taps completed was recorded. Tests were performed in bare or socked feet. Subjects were permitted 2-3 taps for familiarization. This protocol has been described previously in Kent-Braun et al. (1998) and Kent-Braun and Ng (1999). The test proved to have good reliability when used on a healthy population (Appendix G).

Balance Subjects performed 4 balance tasks for a maximum of 20 seconds each.

Task 1: two-legged stance, feet comfortably apart, eyes open.
Task 2: two-legged stance, feet comfortably apart, eyes closed.
Task 3: one-legged stance, (balancing on right leg), eyes open.
Task 2: one-legged stance, (balancing on right leg), eyes closed.

The subject's performance on each task was timed with a stopwatch. Timing stopped immediately when the subject lost balance (i.e., supporting foot/feet moved or free foot touched the ground). If the 20 second maximum time was not achieved on the first attempt, a second attempt was made. The longest time achieved was recorded to the nearest tenth of a second and used for analysis.

The subjects' arms hung by their sides for each task although they were permitted to move away from sides during the tasks to assist with balance. Arms were not, however, permitted to rest against the subject's body (e.g. 'hands on hips'). In one-legged tasks, subjects were asked to raise their left foot backwards from the ground. Timing commenced once the foot left the ground. In task 4, subjects first closed their eyes and then lifted their foot.

No shoes were worn during the performance of the balance tasks. Testing was conducted in an open area where subjects would have no fear of stumbling into obstacles. A spotter was present to assist as necessary. This protocol has been described in Gill et al. (2001) where it was used as one of a series of tests used to objectively assess balance disorders. When used on a young to middle-aged population, however, this test has demonstrated a ceiling effect in scores which may cause an abnormal distribution of data (Appendix G).

Grip strength Grip strength was measured according to the Canadian Physical Activity, Fitness and Lifestyle Appraisal (Canadian Society for Exercise

Physiology, 1996) protocol using a JAMAR hand dynamometer (Sammons Preston, Bolingbrook, IL). Width was adjusted so the dynamometer bar sat between the base of the thumb and the second joint of the fingers. The subject stood with feet comfortably apart and arm slightly away from their body with the dynamometer held in line with the forearm. The subject was instructed to squeeze the dynamometer once, as hard as possible, while exhaling. No bending of the wrist and elbow joints was permitted.

Right and left hands were tested alternately. Two trials were given (i.e., the testing sequence was right, left, right, left). Measurements were taken to the nearest kilogram. The highest measurement for each hand was combined to give a total score. Studies showing the reliability of the grip strength test include those by Fairfax et al. (1995), Hamilton et al. (1994) and Mathiowetz et al. (1984).

Chair stand A stable chair with a seat height of approximately 43 cm (17 inches) was used. The chair did not have arm rests and was positioned with its back resting against a wall to prevent slippage. The subject sat in the middle of the chair with their back straight and arms crossed at the wrists and held against the chest. Feet were comfortably apart and flat on the ground. From this position, the subject rose to a full stand and then returned to a fully seated position as many times as possible within a 30 second time span.

The tester demonstrated the chair stand slowly to show proper form and then at a faster pace to illustrate the objective of the test. The subject was allowed one or two practice stands for familiarization prior to testing. The test was scored according to the number of stands completed in 30 seconds. This test follows the protocol described in the Senior Fitness Test Manual (Rikli and Jones, 2001). Rikli and Jones (1999) found this test to have an acceptable level of reliability.

Chair sit-and-reach The subject sat at the front of a stable, straight-backed chair (seat height of 43 cm) so that the gluteal fold was in line with the front edge of the seat. The right leg was extended with the heel resting on the ground and the sole of the foot approximately at right angles to the leg. No knee flexion was permitted in the right leg during the test. The left leg was bent with the foot flat on the floor. Arms were outstretched with one hand resting on top of the other so that middle fingers were even. The subject slowly reached as far forward as possible towards the toes of their right foot keeping their head in line with their trunk. Once the maximal reach was achieved, the position was held for 2 seconds (counted by the tester).

The test was scored by measuring the distance between the subject's middle finger and the midpoint of the top of the subject's shoe to the nearest centimeter (or half inch). Consequently, if the subject reached the top of their shoe, their score was zero. Those who were not able to reach as far as their shoe had a negative score while those could reach past their shoe had a positive score. A standard 18 or 12 inch ruler (whichever was appropriate) was used for making measurements. Measurements were recorded in both imperial and metric units.

Subjects were given 2 warm up trials followed by 2 test trials. The highest score for the test trials was recorded as their result. Shoes were worn during testing. In the case of subjects wearing open-toed shoes (e.g. sandals), the zero point was taken as a point in line with the sole of the foot. This test protocol is described in the Senior Fitness Test Manual (Rikli and Jones, 2001), although the manual assumes all subjects would be wearing closed-in shoes. Rikli and Jones (1999) found this test to have an acceptable level of reliability.

Back scratch While standing comfortably, the subject put their preferred hand over their same shoulder with the palm facing down. The other hand was placed behind their back with palm facing up. The subject attempted to touch or overlap the middle fingers of each hand.

The test was scored by measuring the distance of overlap between the tips of the 2 middle fingers. If the subject's fingers touched, they received a score of zero. Overlapping fingers received a positive score whilst subjects whose fingers could not touch were given a negative score. A standard 18 or 12 inch ruler (whichever appropriate) was used for making measurements. Measurements were recorded in both imperial and metric units to the nearest half unit.

Subjects were given 2 warm up trials followed by 2 test trials. Warm ups and trials were performed on the subject's prefered side. The highest score for the test trials was recorded as their result. The tester helped the subject align their middle fingers as best as possible without moving the subject's hands. Subjects were not permitted to interlock their hands. This test protocol is described in the Senior Fitness Test Manual (Rikli and Jones, 2001). Rikli and Jones (1999) found this test to have an acceptable level of reliability.

8-foot up and go The subject sat in the middle of a stable, straight-backed chair (seat height of 43 cm) with feet flat on the floor, one foot slightly in front of the other, hands on thighs and trunk leaning slightly forward. On a signal of "go", the subject stood, walked as quickly as possible around a marker placed 8 feet directly in front of chair, returned to the chair and sat back down. The subject could choose to walk either clockwise or anticlockwise around the marker.

The chair was placed with its back against a wall to prevent slippage. The back of the marker was placed in a position measuring 8 feet (2.44 meters) from a point on the floor in line with the front edge of the seat of the chair.

The test was demonstrated to the subject. The subject then had one practice trial followed by two test trials. The fastest time to the nearest tenth of a second was taken as the score. To begin the test, the subject was given a countdown of "3-2-1-go". Timing began on "go" and stopped the moment the subject sat back down on the chair. The subject was not permitted to run to complete the test. This test protocol is described in the Senior Fitness Test Manual (Rikli and Jones, 2001). Rikli and Jones (1999) found this test to have an acceptable level of reliability.

Reaction time The protocol for the reaction time test was taken from the Older Driver Skill Assessment and Resource Guide produced by the American Association of Retired Persons (1998). The guide contains a picture of a driving situation which was presented to the subject. The picture is situated on the lower half of a letter-sized page. The numbers one to fourteen are superimposed onto the picture in a random fashion (Appendix F).

Once the picture was presented to the subject, he/she attempted to find the number "1" and put their finger on it. Once this was achieved, they searched for the number "2" and put their finger on it. The subject continued this process trying to find each of the fifteen numbers in consecutive order.

Subjects were given 10 seconds to locate as many of the numbers as possible. The picture was kept face down in front of the subject until the test protocol had been explained and understood. A description of the approximate position of the first number was given to subjects prior to seeing the picture (i.e., 'top right hand corner'). Timing started as soon as the picture was turned face up. The last number the subject located and touched within the ten second time period was taken as their score. The test, in its current form, is not suitable for reliability testing due to the learning effect that is encountered when subjects repeat the test (Appendix G).

Isokinetic Testing

Prior to testing, subjects warmed up by walking on a treadmill for 3 minutes at a comfortable pace with no incline. Because this data will be used for a study on driving performance, testing was carried out on the right ankle due to its predominant use in driving. Subjects wore socked or bare feet for testing.

Equipment Testing was performed on a Biodex System 3 Professional isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, New York, USA) with Biodex Advantage software (Beta version). The standard Biodex ankle attachment, limb support pad, and foot rest was used. Sensitivity was automatically set for the ankle attachment. Cushioning was set at 1 (hard). The Biodex gravity correction function was not used.

The Biodex sampling frequency is set at 100Hz. Equipment calibration was verified regularly.

Subject positioning Subjects were positioned on the Biodex in a way that simulated, as close as the physical limitations of the Biodex allowed, the position one would be in when driving an average car. To achieve this, subjects were seated with the chair of the Biodex with the right leg elevated by the limb support pad and right foot placed on the footplate. The chair was adjusted to give an approximate hip angle of 85^0-100^0 on their right side and an approximate right knee angle of 120^0 -130^0. The horizontal distance of the leg support pad was adjusted to the comfort of individual subjects so that neither movement nor circulation was impeded.

The axis of rotation of the dynamometer head was aligned with the axis of rotation of the ankle when in the neutral position. Using a hand-held goniometer, a neutral ankle position of 0^0 was determined as the position where the sole of the foot was at 90^0 to the tibia. End points for range of movement were set at 10^0 dorsiflexion and 30^0 plantar flexion (as measured by the Biodex).

To eliminate any extraneous movement during testing, a series of padded straps (standard to the Biodex) were used to secure the subject in position. Two straps crossed diagonally infront of the trunk from the shoulder to the hip. One of these passed from the left shoulder to the right hip and the other from the right shoulder to the left hip. A further strap passed horizontally infront of the trunk at hip level. A strap also passed over the subject's right thigh securing it to the leg support attachment. The straps were tightened as much as possible without causing discomfort to the subject. Furthermore, the tester watched for any extraneous movement and verbally corrected the subject's form.

The subject's foot was secured in the foot plate by the use of two parallel velcro straps. The first strap passed directly over the metatarsal heads. For this, the standard 10 cm strap had the large padding removed and was folded in half longitudinally and used. The second strap was 5 cm in width and crossed the foot as close as possible to the ankle joint without impeding movement or causing discomfort. To enhance the comfort of subjects, padding was placed between the strap and the subject's foot. To improve blood circulation to the foot, the lower strap was loosened during plantar flexion tests while the upper strap was loosened during the dorsiflexion tests. The straps were not needed to secure the foot to the foot plate at these particular times.

During testing, the subject's left leg hung unsupported. However, between testing protocols they were permitted, for comfort, to rest their left foot on the Biodex foot rest. The subject's arms were crossed at the wrists and held against their body during testing, but could be held in a relaxed position between protocols.

The computer monitor was in view of subjects during testing. Although they were not encouraged to watch the monitor while performing tests (with the exception of the passive stiffness test), a brief explanation of the screen display was given.

Order of protocols Gleim and McHugh (1997) point out that passive stretching can decrease passive stiffness for up to one hour. Consequently, warm up, number of repetitions, and activity immediately prior to testing should be considered. With this in mind, passive resistance was tested before isometric strength and rate of torque development.

Passive stiffness The subject's ankle was passively moved from 30^0 of plantar flexion, to 10^0 of dorsiflexion, and back to 30^0 of plantar flexion. This was repeated 6 times at an angular velocity of 5^0/s. Subjects were required to relax during this time avoiding any voluntary muscle contraction that may inhibit or contribute to the movement. If the tester noticed significant voluntary muscle contractions, the test was repeated. This occurred with 8 subjects. Despite this, data from 11 subjects had to be excluded due to muscle involvement which was apparent on the passive resistance curves.

Passive stiffness of the ankle joint was taken as the ankle's passive resistance to movement. To measure this, the average highest and lowest torques recorded for the five most consistent repetitions was calculated. This was typically the last 5 repetitions. The difference between highest and lowest is the passive resistance. In some instances, only 4 repetitions were analysed due to obvious muscle involvement in the fifth. Measurements were recorded in newton meters.

Isometric strength and rate of torque development Subjects were required to perform maximal isometric contractions from a position of 20^0 plantar flexion and then from the neutral position of 0^0. Both plantar and dorsiflexion contractions were performed, the order of which alternated from subject to subject. The subject was given 1 to 2 familiarization trials in each of the two positions for both plantar flexion and dorsiflexion. For these trials they were asked to give a submaximal effort for approximately 3 seconds. The familiarization trials also gave the tester an opportunity, if needed, to adjust foot and ankle straps prior to testing.

To perform the test, the subject's ankle was first moved into a position of 20^0 plantar flexion. On a signal of "fast" from the tester, the subject gave a maximal isometric contraction (either plantar flexion or dorsiflexion) which was sustained for a period of 7 seconds. The tester verbally signalled the subject when the 7 seconds had elapsed. This procedure was performed 3 times with a 1 minute rest period between each contraction. The subject's ankle was then moved into the neutral position of 0^0 and a further 3 maximal isometric contractions were performed with 1 minute rest intervals between each repetiton. After a one minute rest, the above protocol was repeated with the subject performing contractions in the opposite direction.

In order to achieve a maximal voluntary contraction with a maximal rate of force development , subjects were instructed to contract the appropriate muscle groups 'fast'. The instruction of 'fast' has been shown to elicit a higher rate of force development than the instruction of 'hard-and-fast' without significantly affecting the maximal voluntary contraction (Salhaly et al., 2001). Subjects were reminded to contract *fast* immediately prior to each contraction.

Peak torque (PT) and rate of torque development (RTD) were collected for analysis for both plantar flexion and dorsiflexion in each of the two positions. Peak torque was considered to be the highest torque achieved during the three repetitions. This value was obtained using the cursor on the curve analysis screen of the Biodex software.

RTD over the time taken to reach 90% of PT was calculated. This was done by calculating 90% of the largest PT achieved by the subject (T_{90}) and then, using the cursor, establishing the time taken to reach that torque (t_{90}). Torque was divided by time to give RTD. i.e.:

$$\mathrm{RTD} = \frac{T_{90}}{t_{90}}$$

This method of calculation was used in attempt to minimize error that may occur due to torque artifact which can influence the identification of PT. RTD was measured in $\mathrm{Nm.s^{-1}}$.

Statistical Analysis

Field vs laboratory Each of the functional tests was paired with one or more of the parameters measured on the Biodex. Pairings were made between those which are most likely to be related. For example, foot tapping requires fast movement so it was paired with RTD in anticipation that they may be statistically related. Speed of foot tapping may also be affected by the stiffness of the ankle and so it was also paired with PS. The following pairs were made:

- PS and foot tapping
- PS and balance
- PS and chair stand
- PS and sit-and-reach
- PS and back scratch
- PS and 8-foot up and go
- RTD and foot tapping
- RTD and balance
- RTD and grip strength
- RTD and chair stand
- RTD and 8-foot up and go
- RTD and reaction time
- PT and balance
- PT and grip strength
- PT and chair stand
- PT and 8-foot up and go

The relationship between these pairs was analysed by calculating Pearson's correlation coefficient. Multiple regression was performed to determine which field tests were the strongest predictors of each laboratory measurement (i.e., PT, RTD and PS). This was done using SigmaStat (version 3.0) Best Subsets regression.

Age and Sex For all variables measured, a two-way analysis of variance was performed with age and gender as factors to determine differences between the younger and older subjects and between men and women. Significant interactions were further investigated using a Holm-Sidak post hoc test to determine differences. Statistical analysis was performed using SigmaStat (version 3.0) statistical package. The significance level for all analyses was set at $p<.05$.

Data was not available for all 57 subjects for all tests (Table 1). Due to high blood pressure measurements, three subjects were excluded from all isokinetic tests and from strenuous field tests. A further one balance, one grip strength, one dosiflexion and three back scratch measurements were not made due subjects' pain or discomfort. In addition, isokinetic data was reduced by a further one entry for plantar flexion measurements (due to extraneous muscle involvement) and 2 entries for dorsiflexion measurements (due to subjects inability to generate enough force to register a measurement - at 0^0 only). Most detrimental to the isokinetic data was the exclusion of a further 11 passive stiffness results due to the shape of the curves produced on the Biodex suggesting subjects were not relaxed during the test. Consequently those eleven measurements are not valid indicators of passive stiffness and were not further analysed.

The balance test demonstrated a strong ceiling effect with all subjects achieving the maximal score for tasks 1 and 2. Tasks 3 and 4 showed some variation although the data still did not follow a normal distribution. Data for task 3 appeared to be closest to a normal distribution and so only the results for task 3 were analysed.

Table 1 Number of missing data points for each test.

	young women	*young men*	*older women*	*older men*
height				
weight				
foot tap				
balance				1
grip				2
chair stand			2	1
sit & reach				
back scratch			1	2
up & go				
reaction time				
PS	2	4	5	3
PT pf0^{0}	1		2	1
PT pf20^{0}	1		2	1
PT df0^{0}			4	2
PT df20^{0}			2	2
RFD pf0^{0}	1		2	1
RFD pf20^{0}	1		2	1
RFD df0^{0}			4	2
RFD df20^{0}			2	2

RESULTS

The physical characteristics of the subjects who participated in this study are presented in Table 2. Analysis of variance calculations showed a significant age and sex effect on height and weight measurements, i.e., men were taller and heavier than women, and younger subjects were taller and heavier than older subjects. There was no age x gender interaction.

Table 2 Physical characteristics of study participants showing the mean and the standard deviation.

	young women	*young men*	*older women*	*older men*
number (n)	14	16	13	14
age (yr)	41.1 ± 7.0	38.6 ± 6.3	76.2 ± 5.6	75.9 ± 4.5
height [a,b] (m)	1.66 ± 0.06	1.75 ± 0.07	1.61 ± 0.05	1.73 ± 0.05
weight [a,b] (kg)	80.4 ± 17.4	91.4 ± 17.2	69.2 ± 11.5	82.1 ± 11.9
activity level (Grimby)*	4	5	4	4

[a] A significant age difference exists. ($p<0.05$)

[b] A significant sex difference exists. ($p<0.05$)

Note: * median value

A Kruskal-Wallis one way analysis of variance on ranks concluded there were no significant differences in activity level between the groups. There was a high amount of variability between individual subjects with the activity levels of both the younger and older groups covering the full range of the Grimby scale. Activity types were surprisingly similar for both groups with walking, yardwork/gardening and resistance training featuring most commonly. However, younger subjects reported participating in high intensity activities such as running, cycling and sporting activities more than older subjects. Older subjects stretched more regularly than younger subjects.

Age and Sex Differences for the Field and Isokinetic Tests

Analysis of variance results are presented in Tables 3 and 4. A significant age effect occurred in all but one of the field tests with younger subjects generally scoring better than older subjects. Younger subjects could balance longer, demonstrated a stronger grip strength, had more upper body flexibility, and were faster at foot tapping, chair stand, up and go and reaction time tests. Chair sit-and-reach was the only field test where age appeared to have no effect on performance. Chair sit-and-reach did, however, have a significant sex effect with women demonstrating more lower body flexibility than men. Grip strength results also had a gender effect with men scoring higher than women. An age x sex interaction was only apparent in reaction time results. Apart from the main effect of age, whereby younger subjects demonstrated faster reaction times than older subjects, the interaction revealed that young women scored significantly higher than young men. There was no significant difference between older men and women.

Results for isokinetic tests showed a significant sex difference in all measurements with the exception of RTD for pf0^0. Apart from this one measurement, scores revealed that women had less stiffness in their ankle than men, that men had greater ankle strength than women, and that men were capable of developing force around the ankle joint more rapidly than women. This occurred in both plantar flexion and dorsiflexion.

An age effect was significant for only dorsiflexion in the 20^0 position. The difference occurred in both peak torque and RTD whereby younger subjects had higher peak torques and RTD than older subjects at df20^0.

Correlations

Table 5A provides results for correlation analyses. Table 5B provides the same analyses but calculated using the results of the older subjects only. Passive stiffness correlated significantly with only the back scratch test. This correlation was not significant for the older subjects. In fact, PS did not correlate with any of the field tests for the older group, although it must be noted that there were only results for 19 older subjects for PS.

For the total sample, all PT measurements correlated positively with balance and grip strength and negatively with the up and go test. Although all peak torque correlations were significant, those with grip strength were consistently stronger than the others. Similar results were found for the older group although the correlations were not significant between balance and PT for df20^0, up and go and PT for pf0^0, and up and go and PT for df20^0. Apart from these exceptions, correlations for the older subjects were stronger than those for the whole sample.

RTD had a significant negative correlation with the up and go test for all positions and directions. There were also positive correlations between RTD and balance and between RTD and chair stand except for the pf20^0 and pf0^0 positions respectively. Results were similar for older subjects although correlations were not significant for balance and RTD for df20^0, up and go and RTD for df0^0, up and go and RTD for df20^0, and grip strength and RTD for pf0^0. Results for older subjects did have a significant correlation between chair stand and RTD for pf20^0 which was not present for the total sample. Significant correlations for the older subjects were stronger than those for the whole sample.

Pearson's correlation was also used to investigate the relationships between the field tests themselves. Correlation coefficients were calculated for the total sample (Table 6A) and for the older subjects (Table 6B). There were fewer significant correlations for the older subjects as compared to the total sample, however, the tables showed a number of similarities. In both tables, the physical characteristics of height and weight showed a strong relationship with grip strength. The two flexibility tests - the chair sit and reach and the back scratch - also demonstrated a good relationship to each other as did the balance test with the 8-foot up and go (a test of agility and dynamic balance).

A Spearman rank order correlation was performed to investigate the influence of activity levels (according to the Grimby scale) on the isokinetic measures. For the older subjects, a significant correlation was found only with RTD for dorsiflexion in the 0^0 position ($r=0.57$; $p<0.01$). This relationship was just beyond significance in the total sample but was significant for dorsiflexion PT in the same position ($r=0.31$; $p<0.05$).

Multiple Regression

Multiple regression results are displayed in Tables 7 to 11. The back scratch test proved to be the best single predictor of PS. However, when the up and go results were added to the regression model, the adjusted R^2 value increased substantially to a value of 0.31 (Table 7A). For the older adults, the chair stand test was the only predictor of PS although it was not statistically significant (Table 7B).

The grip strength test was found to be the best predictor for all peak torque measurements with adjusted R^2 values ranging from 0.29 to 0.55 for the whole sample (Table 8A) and from 0.60 to 0.78 for the older subjects (Table 8B). In all cases, the p values were <0.001. Adjusted R^2 values did not significantly increase, for the whole sample, when other field tests were added into the regression model. For older subjects, the chair stand test did significantly increase the adjusted R^2 value for dorsiflexion in the 0^0 position.

The grip strength test also proved to be the best predictor of RTD for both plantar and dorsiflexion in all positions (Table 9A) with a p value <0.001. Although the adjusted R^2 value increased when other field tests were added to the model, none made a statistically significant contribution (see tables 10 and 11 for examples). For older subjects, grip strength was the best predictor of RTD for dorsiflexion only (Table 9B) . For plantar flexion, the variation in scores was best explained by the chair stand test for the 0^0 position and by the up and go test for the 20^0 position ($p<0.01$). No other field test made a significant contribution.

Multiple regression analysis was repeated using the physical characteristics of age, weight, height and activity level as variables in addition to those field tests which had already proved to make a significant contribution to the explanation of variation. Field tests did not significantly explain any of the variation in PS results for older adults and so the regression analysis, in this case, was repeated using only physical characteristics as variables. As a result, height accounted for 23% of the variation in older adult PS. In all other cases, the field tests continued to be the strongest predictors of the isokinetic measurements although height, weight and age also made significant contributions in a number of instances. For the total sample, height and/or weight contributed to all regression models apart from RTD for plantar flexion (Table 12A). Physical characteristics appeared to have less influence on the ankle performance of older adults with only the regression models for dorsiflexion PT being influenced by their inclusion (Table 12B). However, it should be noted that the addition of these variables to the PT dorsiflexion regression models for older subjects enabled nearly all of the variation to be explained with an adjusted R^2 value of 0.91 for df0^0 and 0.93 for df20^0.

Table 3 **Age and sex differences for field tests using two-way ANOVA showing the mean and standard deviation*.**

	young women n = 14	*young men n = 16*	*older women n = 13*	*older men n = 14*
foot tap [a] (taps)	40.5 ± 6.9	39.9 ± 5.9	31.5 ± 6.0	34.1 ± 3.9
balance [a] (s)	19.2 ± 2.2	19.7 ± 1.2	10.4 ± 7.3	13.5 ± 7.9 (1)
grip [a,b] (kg)	54.2 ± 8.5	93.3 ± 26.7	41.9 ± 11.9	77.7 ± 14.2 (2)
chair stand [a] (#)	14.7 ± 2.8	16.1 ± 3.2	10.5 ± 4.5 (2)	12.3 ± 3.2 (1)
sit & reach [b] (cm)	1.8 ± 4.8	-0.1 ± 5.8	0.3 ± 4.7	-3.6 ± 4.5
back scratch [a] (cm)	0.8 ± 4.3	-0.8 ± 3.2	-3.1 ± 4.6 (1)	-5.5 ± 5.0 (2)
up & go [a] (s)	4.5 ± 0.5	4.0 ± 0.3	5.9 ± 0.9	5.8 ± 2.2
reaction time [a,c] (#)	9.6 ± 1.9	8.0 ± 2.1	6.2 ± 2.0	7.2 ± 2.4

[a] A significant age difference exists. ($p<0.05$)

[b] A significant sex difference exists. ($p<0.05$)

[c] A significant age x sex interaction exists. ($p<0.05$)

* Numbers in parenthesis indicate the number of subjects that did not complete the test (see Table 1).

Table 4 **Age and sex differences for isokinetic tests using two-way ANOVA showing the mean and standard deviation*.**

	young women n = 14	*young men n = 16*	*older women n = 13*	*older men n = 14*
PS [b] (Nm)	8.9 ± 3.0 (2)	11.9 ± 2.7 (4)	9.0 ± 2.3 (5)	11.3 ± 2.2 (3)
PT pf0^0 [b] (Nm)	65.2 ± 29.7 (1)	100.4 ± 35.1	45.9 ± 23.3 (2)	92.3 ± 36.4 (1)
PT pf20^0 [b] (Nm)	42.2 ± 19.2 (1)	59.2 ± 19.5	30.5 ± 11.1 (2)	53.0 ± 19.4 (1)
PT df0^0 [b] (Nm)	14.2 ± 6.0	28.9 ± 6.9	12.9 ± 6.4 (4)	25.4 ± 8.1 (2)
PT df20^0 [a,b] (Nm)	24.8 ± 5.4	42.5 ± 8.2	18.6 ± 6.0 (2)	37.4 ± 9.4 (2)
RTD pf0^0 (Nm/s)	174.7 ± 79.8 (1)	292.3 ±140.5	185.3 ± 152.9 (2)	203.5 ±105.8 (1)
RTD pf20^0 [b] (Nm/s)	131.0 ± 54.8	202.3 ± 94.5	119.3 ± 91.4 (2)	161.9 ± 93.4 (1)
RTD df0^0 [b] (Nm/s)	72.0 ± 29.2	121.7 ± 39.0	52.4 ± 36.6 (4)	104.7 ± 39.4 (2)
RTD df20^0 [a,b] (Nm/s)	97.3 ± 32.3	151.5 ± 39.6	81.2 ± 45.0 (2)	122.3 ± 32.2 (2)

[a] A significant age difference exists. ($p<0.05$)

[b] A significant sex difference exists. ($p<0.05$)

[c] A significant age x sex interaction exists. ($p<0.05$)

* Numbers in parenthesis indicate the number of subjects that did not complete the test (see Table 1).

Table 5A Field tests versus isokinetic test - Pearson's correlation coefficients for all subjects.

	height	*weight*	*foot tap*	*bal.*	*chair stand*	*sit & reach*	*back s.*	*up & go*	*grip*	*r.t ime*
PS	0.35	0.45	NS	NS	NS	NS	-0.46	NS	-	-
RTD pf0^0	0.34	0.31	NS	NS	0.36	-	-	-0.42	0.47	NS
pf20^0	0.28	NS	NS	0.37	NS	-	-	-0.48	0.44	NS
df0^0	0.59	0.38	NS	0.38	0.38	-	-	-0.35	0.66	NS
df20^0	0.50	0.58	NS	0.33	0.32	-	-	-0.37	0.61	NS
PT pf0^0	0.60	0.33	-	0.36	0.28	-	-	-0.35	0.56	-
pf20^0	0.56	0.39	-	0.38	0.30	-	-	-0.39	0.57	-
df0^0	0.70	0.56	-	0.28	0.35	-	-	-0.38	0.70	-
df20^0	0.72	0.71	-	0.29	0.38	-	-	-0.35	0.75	-

NS = not significant, i.e., $p>.05$

- = correlation not performed

Table 5B Field tests versus isokinetic test - Pearson's correlation coefficients for older adults.

	height	***weight***	***foot tap***	***bal.***	***chair stand***	***sit & reach***	***back s.***	***up & go***	***grip***	***r. time***
PS	0.52	NS	NS	NS	NS	NS	NS	NS	-	-
RTD **$pf0^0$**	NS	NS	NS	NS	0.65	-	-	-0.5	NS	NS
$pf20^0$	NS	NS	NS	0.48	0.45	-	-	-0.55	0.44	NS
$df0^0$	0.63	NS	NS	0.53	0.47	-	-	NS	0.71	NS
$df20^0$	0.44	0.49	NS	NS	0.43	-	-	NS	0.56	NS
PT **$pf0^0$**	0.67	0.43	-	0.43	0.51	-	-	NS	0.79	-
$pf20^0$	0.66	0.50	-	0.46	0.55	-	-	-0.43	0.79	-
$df0^0$	0.73	0.64	-	0.46	0.69	-	-	-0.52	0.88	-
$df20^0$	0.80	0.80	-	NS	0.55	-	-	NS	0.88	-

NS = not significant, i.e., $p>.05$

\- = correlation not performed

Table 6A **Pearsons correlation coefficients showing the relationship between field test results for all subjects.**

	weight	*foot tap*	*balance*	*grip*	*chair stand*	*sit & reach*	*back scratch*	*up & go*	*reaction time*
height	0.52***	0.28*	0.36**	0.61***	NS	NS	NS	NS	NS
weight	-	0.35**	NS	0.48***	NS	NS	NS	NS	NS
foot tap	-	-	0.31*	0.32*	NS	NS	NS	-0.31*	0.39**
balance	-	-	-	0.42**	0.41**	NS	0.37**	-0.72***	0.34*
grip	-	-	-	-	0.29*	NS	NS	-0.38**	NS
chair stand	-	-	-	-	-	NS	0.36**	-0.68***	NS
sit & reach	-	-	-	-	-	-	0.53***	-0.26*	NS
back scratch	-	-	-	-	-	-	-	-0.49***	0.27*
up & go	-	-	-	-	-	-	-	-	-0.32*

$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$

Table 6B **Pearsons correlation coefficients showing the relationship between field test results for older subjects.**

	weight	*foot tap*	*balance*	*grip*	*chair stand*	*sit & reach*	*back scratch*	*up & go*	*reaction time*
height	0.62***	NS	NS	0.77***	NS	NS	NS	NS	NS
weight	-	0.45*	NS	0.55**	NS	NS	NS	NS	NS
foot tap	-	-	NS	NS	NS	NS	NS	NS	NS
balance	-	-	-	0.53**	NS	NS	NS	-0.59**	NS
grip	-	-	-	-	0.44*	NS	NS	NS	NS
chair stand	-	-	-	-	-	NS	NS	-0.65***	NS
sit & reach	-	-	-	-	-	-	0.52**	NS	NS
back scratch	-	-	-	-	-	-	-	-0.45*	NS
up & go	-	-	-	-	-	-	-	-	NS

*p <0.05; **p <0.01; ***p <0.001

Table 7A **Multiple regression results for passive stiffness for all subjects.**

Model	*Adjusted R^2*
back scratch**	0.22
back scratch*** + up&go*	0.31

*p <0.05; **p <0.01; ***p <0.001

Table 7B **Multiple regression results for passive stiffness for older adults.**

Model	*Adjusted R^2*
chair stand	0.03

Table 8A **Multiple regression results for peak torque at pf0^0, pf20^0, df0^0, and df20^0 for all subjects.**

Contraction		*Model*	*Adjusted R^2*
plantar flexion	**0^0**	grip strength***	0.29
	20^0	grip strength***	0.30
dorsiflexion	**0^0**	grip strength***	0.48
	20^0	grip strength***	0.55

*p <0.05; **p <0.01; ***p <0.001

Table 8B **Multiple regression results for peak torque at pf0^0, pf20^0, df0^0, and df20^0 for older subjects.**

Contraction		*Model*	*Adjusted R^2*
plantar flexion	**0^0**	grip strength***	0.60
	20^0	grip strength***	0.60
dorsiflexion	**0^0**	grip strength***	0.48
		grip strength***+ chair stand*	0.82
	20^0	grip strength***	0.76

*p <0.05; **p <0.01; ***p <0.001

Table 9A Multiple regression results for rate of torque development at pf0^{0}, pf20^{0}, df0^{0}, and df20^{0} for all subjects.

Contraction		*Model*	*Adjusted R^2*
plantar flexion	**0^{0}**	grip strength***	0.19
	20^{0}	grip strength***	0.30
dorsiflexion	**0^{0}**	grip strength***	0.42
	20^{0}	grip strength***	0.35

*p <0.05; **p <0.01; ***p <0.001

Table 9B Multiple regression results for rate of torque development at pf0^{0}, pf20^{0}, df0^{0}, and df20^{0} for older subjects.

Contraction		*Model*	*Adjusted R^2*
plantar flexion	**0^{0}**	chair stand**	0.35
	20^{0}	up & go**	0.35
dorsiflexion	**0^{0}**	grip strength***	0.48
	20^{0}	grip strength**	0.27

*p <0.05; **p <0.01; ***p <0.001

Table 10 **Multiple regression results for rate of torque development at pf20^0 for all subjects.**

Model	*Adjusted R^2*
grip strength***	0.30
grip strength***+ foot tap	0.33
grip strength***+ foot tap + reaction time	0.36
grip strength*** + foot tap + reaction time + up & go	0.38

*p <0.05; **p <0.01; ***p <0.001

Table 11 **Multiple regression results for rate of torque development at df0^0 for all subjects.**

Model	*Adjusted R^2*
grip strength***	0.42
grip strength***+ chair stand	0.43
grip strength***+ chair stand + up & go	0.43
grip strength***+ chair stand + up & go + balance	0.46

*p <0.05; **p <0.01; ***p <0.001

Table 12A Multiple regression results for all subjects including physical characteristics as variables.

Contraction	*Model*	*Adjusted R^2*
PS	back scratch** + weight*	0.31
PT pf0^0	grip strength* + height**	0.39
pf20^0	grip strength* + height*	0.36
df0^0	grip strength** + height** + weight*	0.63
df20^0	grip strength*** + height** + weight***	0.75
RTD pf0^0	grip strength***	0.20
pf20^0	grip strength**	0.18
df0^0	grip strength*** + height*	0.47
df20^0	grip strength*** + weight**	0.44

*p <0.05; **p <0.01; ***p <0.001

Table 12B Multiple regression results for older subjects including physical characteristics as variables.

Contraction		*Model*	*Adjusted R^2*
PS		height*	0.23
PT	**pf0^0**	grip strength***	0.60
	pf20^0	grip strength***	0.60
	df0^0	grip strength***+age***+weight*	0.91
	df20^0	grip strength*+age*+height*+weight***	0.93
RTD	**pf0^0**	chair stand***	0.40
	pf20^0	up and go**	0.27
	df0^0	grip strength***	0.48
	df20^0	grip strength**	0.27

*p <0.05; **p <0.01; ***p <0.001

DISCUSSION

Results from this study, in general, support the 3 hypotheses. For the first hypothesis, multiple regression and correlation calculations showed some good relationships between field tests and PT and RTD of the ankle suggesting that field testing may be used as an alternative means of assessing these two physical characteristics. No suitable field test was found for assessing PS.

In terms of the second hypothesis, results showed no statistically significant age effect for the isokinetic tests except for dorsiflexion PT and RTD in the 0^0 position. However, compared to younger subjects, older subjects did have lower mean PT and RTD values apart from RTD pf0^0 for women. Passive stiffness mean scores were very similar for older and younger subjects.

For the third hypothesis, the expected sex differences for isokinetic tests were evident in the results. These differences were all statistically significant with the exception of RTD for pf0^0.

Results will be discussed in more detail in relation to each of the 3 hypotheses:

Hypothesis 1

- ***Selected field tests can be used as an alternative means of***

assessing passive stiffness, isometric strength, and rate of torque development in both the plantar and dorsiflexors of the ankle in older adults

Good relationships were found between the field tests chosen for the study and isokinetic tests, with the exception of PS. Relationships were strongest with older adults - possibly because a number of the chosen field tests were developed specifically for an older population (Rikli and Jones, 2001). These results suggest that it may be possible to use simple field tests as an alternative to isokinetic dynamometry - particularly for older adults.

Isometric strength Multiple regression results and Pearson's correlation coefficients showed a strong relationship between grip strength and PT for both PF and DF indicating that grip strength is a predictor of ankle strength. Adjusted R^2 values ranged from 0.60 to 0.78 for older subjects. Values were similar for both the 0^0 and 20^0 positions suggesting that grip strength reflects overall ankle strength rather than strength in only a specific position. Grip strength has demonstrated significant correlations with isometric strength of other muscle groups such as those responsible for elbow, knee and trunk movement (Rantanen et al., 1994). It has also been reported to have declines with age similar to those in other body sites (Kallman et al., 1990). Consequently, grip strength testing has been used as an indicator of overall strength (Kallman et al., 1990; Rantanen et al., 1999).

The adjusted R^2 values were higher for dorsiflexion showing the relationship between grip strength and PT is stronger in dorsiflexion than plantar flexion. It is possible that this is related to differences in the reliability of testing PF strength as compared to DF. Thelen et al. (1996) noted that variability of PT and RTD measures across repeated trials was less in DF than PF. A practice effect was also noted whereby some subjects significantly improved their performance between the first and third trial of maximal isometric contractions in PF. This did not significantly occur in DF trials. Good reliability for DF (Holmbäck et al., 1999) and PF (Morris-Chatta et al., 1994) isokinetic strength testing of the ankle has been demonstrated, however, no similar studies for isometric strength testing (using an isokinetic dynamometer) have been located. A visually obvious difference between PF and DF performance during testing is the tendency for subjects to attempt to use extraneous movements when performing maximal plantar flexion contractions. This does not occur in dorsiflexion. Muscles involved in dorsiflexion can be well isolated by subject positioning and the use of stabilizing straps as described earlier. In contrast, extraneous muscle involvement is difficult to eliminate when performing maximal plantar flexion contractions. Most common is the use of hip extension to enhance performance. Despite the use of stabilizing straps and verbal instructions, it can be difficult to completely eliminate these movements when subjects are required to perform maximal contractions. Consequently, there is higher variability in results which possibly contributes to the lower statistical relationships with plantar flexion. In an early study on isokinetic ankle testing, Öberg et al. (1987) found that higher standard deviations occurred in torque values when the trunk was not immobilized - allowing extraneous movements to occur.

In all cases, grip strength was the best predictor of dorsiflexor and plantar flexor strength. The chair stand test added to the multiple regression model for $df0^0$ in older adults increasing the adjusted R^2 value from 0.48 to 0.82. The chair stand has proved to be a reliable and valid test of lower body strength in older adults (Jones et al., 1999). Because of strength changes that occur with aging (Porter et al., 1995), older adults have a lower strength threshold than younger adults for whom the chair stand test is likely to be more a test of muscular endurance than muscular strength. Therefore, it is not surprising that the chair stand contributed to the multiple regression model for older adults but not for younger.

Grip strength has been linked with body mass - or more specifically, muscle mass - with lower mass being associated with lower strength (Kallman et al., 1990). In fact, Rantanen et al. (1998) found that weight loss was a predictor of declines in grip strength. In the current study, body mass was also associated with grip strength. Grip strength had a significant correlation with body weight for both the total subject sample ($r=0.61$; $p<0.001$) and for the older subjects ($r=0.55$; $p<.01$). However, when body weight was added to the multiple regression analysis for peak torque, grip strength was still the strongest predictor of PT for both older and younger subjects in PF and DF.

Rate of torque development Grip strength was the best indicator of RTD when results for all subjects were considered (Table 9A). No other field test contributed to the regression model. The relationships between grip strength and RTD were not as strong as those with PT but were, again, generally stronger for the older adults. RTD scores covered a much larger range than did PT. Consequently, a larger subject sample would possibly show more convincing relationships.

For older adults, multiple regression showed grip strength to be the best predictor for dorsiflexion RTD with adjusted R^2 values equalling 0.48 at the 0^0 position and 0.27 at 20^0 (Table 9B). For plantar flexion, multiple regression showed the chair stand and up and go tests to be the best indicators for older adults with the chair stand explaining 35% of the variation at 0^0 and the up and go explaining 35% of the variation at 20^0. Both of these field tests involve a time component and so fast plantar flexion contractions would serve to enhance performance. The relationship between the chair stand test and the up and go test was also good with a correlation coefficient of -0.65 ($p<0.001$). Interestingly, a similar study involving the leg extensors found timed chair rises and walking speed both significantly correlated with leg extensor power (Bassey et al., 1992). Bassey also found a significant correlation between chair rising and walking speed.

Passive stiffness When results for the total study sample were analysed, the back scratch test proved to significantly correlate with PS of the ankle (r=-0.46). The back scratch was also the best predictor of ankle PS accounting for 22% of the variation in scores. The up and go test further contributed explaining another 9% of the variation.

Passive resistance results for the older group, however, did not demonstrate convincing relationships with the chosen field tests. Multiple regression analysis found no significant predictors of PS and no significant correlations were found. This is likely related to the much smaller amount of useable data collected for the older group. As noted earlier, 8 of the 27 older subjects were unable to provide PS curves suitable for analysis (see Table 1). To ensure valid data, passive stiffness studies typically use electromyography to provide feedback for subjects during testing sessions (e.g., Porter et al., 1996). This was not done in the current study. In addition, 3 older subjects did not perform the back scratch test. As a result, the sample of older adults was significantly reduced for PS testing.

It is also probable that no relationship was found between PS and the field tests because of the dissimilarity of the tests themselves. The field tests chosen for this study are typically used to assess the flexibility of the shoulder and the hamstrings (Rikli and Jones, 2001). As previously stated, stiffness and flexibility are not synonymous. Furthermore, Chesworth and Vandervoot (1989) suggest that PS may be joint specific. Consequently, the back scratch and chair sit-and-reach may not reflect the stiffness of the ankle.

Activity levels According to multiple regression and Spearman rank order correlations, activity levels (based on the Grimby scale) do not appear to greatly influence the isokinetic results in this study. However, those correlations that were significant, all involved DF in the 0^0 positon suggesting that physical activity levels may possibly effect an individual's performance of dorsiflexion in the neutral position.

Hypothesis 2

- ***Younger adults would have significantly greater isometric ankle strength, significantly lower ankle passive stiffness and a faster rate of torque development than older adults***

Mean PT and RTD values were lower in older subjects as compared to their younger counterparts with the exception of RTD $pf0^0$ for women. However, the differences were not statistically significant apart from measurements taken for $df20^0$. Mean peak torque values for dorsiflexion, were not out of line with those measured by Thelen et al. (1996) and Vandervoort and McComas (1986). However, in comparison, plantar flexion means were much lower in this study. Although a precise comparison can not be made due to differences in age grouping, mean $pf0^0$ scores for this study were approximately 50-55% of those of similarly aged subjects in both the Thelen et al. (1996) and Vandervoort and McComas (1986) studies with the exception of older men who were closer to 70%. Both Thelen et al. (1996) and Vandervoort and McComas (1986) measured PF in a position previously shown to enable maximal torques to be developed (Sale et al., 1982) accounting for the higher scores.

In the case of RTD, past studies have shown that when relative measurements are used (i.e., RTD is calculated for a certain percentage of the subjects' maximal PT), differences in RTD due to age are minimized (Thelen et al., 1996; Kent-Braun and Ng, 1999). Consequently, age differences were more difficult to detect. Using a similarly sized sample, Thelen et al (1996) found age differences were significant when RTD was calculated as an absolute measurement but lost their statistical significance when RTD was calculated relative to the individual's maximal voluntary strength. Furthermore, RTD results had a large amount of variability which was reflected in the high standard deviations (Table 4). More homogeneous groups, perhaps of similar activity levels, may have led to statistically significant age differences.

When investigating age differences in young and old adults, the term 'young' is commonly used to describe subjects in their twenties to thirties (e.g. Lanza et al., 2003; Vandervoort and Hayes, 1989). In the current study, the younger group ranged in age from 30 to 50 years. According to age classifications defined by Shephard (1997), this group actually crosses into the 'middle age' category. It is possible that the subject sample used in this study was not large enough to detect age differences in strength and RTD between age groups this close together. Sepic et al. (1986) was, similarly, unable to detect differences in mean PF and DF torque measurements between groups aged 25 - 35 years and 50 - 60 years.

The single RTD result showing older women scored higher than the younger women for $pf0^0$, was an abnormality. It is likely that the large variability in scores, heterogeneous nature of the sample, and the narrow separation between age groups all contributed to this result.

Passive stiffness mean scores were very similar between the two age groups for both women and for men suggesting that aging has no effect on PS of the ankle. Because of the reduced number of subjects - particularly older subjects - that participated in the PS testing, these results must be viewed with some caution. However, as previously discussed, studies investigating the relationship between age and ankle PS have provided conflicting results. In line with the current study, Chesworth and Vandervoort (1989) did not find an age related change in passive ankle stiffness. Blanpied and Schmidt (1993), similarly, suggested there was no age effect although their results were not conclusive. It should also be pointed out that these, and similar ankle stiffness studies, have not used large subject samples. Perhaps if future studies were to address this limitation, a more definitive picture of the effect of aging on ankle stiffness may be achieved.

Hypothesis 3

- **Sex differences in strength, passive stiffness and rate of force development would be significant in both the older and younger age groups**

Sex differences were consistent throughout the isokinetic data. Results showed men were stronger and could develop force more quickly than women for both plantar and dorsiflexion. These results are in agreement with other studies on ankle strength and torque development (Vandervoort and McComas, 1986; Vandervoort et al., 1992a; Sepic et al., 1986). Gender differences in this study were all statistically significant with the exception of RTD for $pf0^0$. As discussed above, RTD results covered a wide range of values with those for $pf0^0$ having the widest range and the largest standard deviations. This would make group differences particularly difficult to identify using a sample of this size.

As expected, women had less PS than men. Using a sample of 214 middle-aged and elderly men and women, Vandervoort et al. (1992a) similarly found men had greater passive resistive torque than females. The authors suggest this may be related to differences in muscle size.

Field tests

A direct hypothesis was not made regarding field tests and possible sex and age differences. However, since field tests were expected to be related to PT, RTD and PS measurements, it is logical that field tests would also be expected to have the same predicted sex and age effects as the isokinetic tests.

As anticipated, nearly all field tests exhibited a significant age effect with younger subjects scoring better than the older subjects. The one exception was the chair sit-and-reach where, although mean scores were better for younger subjects, the difference was not significant. Sex differences were only significant for grip strength and chair sit-and-reach. Age and sex outcomes for other studies that have used these field tests are reported below.

Foot tapping Kent-Braun and Ng (1999) found reduced foot tapping speed in elderly men and women (72 ± 1 years old) as compared to young men and women (32 ± 1 years old) in a sample of 48 adults. No sex effect was found. These results are in line with the current study. Gabbard and Hart (1993) used a similar test to investigate age differences in foot tapping speed in children aged 4 to 6 years. Although results do not directly apply to the population used in the current study, Gabbard and Hart did find an age effect with the older children performing better than the younger children. It is likely that foot tapping speed, like other motor skills, improves throughout childhood before reaching its peak. After that, it would seem, performance declines with further aging. No other comparable studies were found. Although foot tapping has been used in studies investigating motor neuron performance, it appears it has not otherwise been used to determine age and sex differences in older adults.

Balance The balance test consisted of 4 stance tasks taken from a larger set of 14 balance tasks which included stance-related tasks and gait tasks (Gill et al., 2001). The complete test battery looked at the sway of the subject as they performed each task. The balance test, as it was used in the current study, produced abnormally distributed data due to the ceiling effect that was encountered. As previously stated all subjects were able to balance for the maximal time in tasks 1 and 2 of the balance test. In task 3, 36 of the 57 subjects could balance for the maximal time of 20 seconds. Of those who were unable to complete the full 20 seconds, 18 were from the older group and only 3 from the younger group. In the more difficult task 4, 9 subjects were still able to balance for the maximal time. All of these subjects were from the younger group. Despite the abnormal distribution of the data, results still show that younger subjects were better at balancing on one leg than older subjects. Furthermore, Lichtenstein et al. (1990) and El Kashlan et al. (1998) both found that clinical tests, including the duration of one-legged stance, had a good association with other more complex methods of balance assessment.

There are a number of studies that have used a timed one legged stance test to show a deterioration in balance (e.g., Gill et al., 2001; El Kashlan et al., 1998; Iverson et al., 1990; Choy et al., 2003; Bohannon et al., 1984; Balogun et al., 1994; Briggs et al., 1998). Some of these studies use a maximal time limit of 30s rather than 20s (eg. Iverson et al., 1990; Briggs et al., 1998) which may reduce the ceiling effect. Interestingly, Balogun et al. (1994) found that in a sample of 1280 subjects between the ages of 6 and 85, balance performance actually improved with age up to a certain point and thereafter progressively declined. For men this turning point occurred in their 30's and for women in their 40's. This concept of a turning point where balance performance starts to deteriorate is supported in research by Choy et al. (2003) and Balogun et al. (1997).

According to Shephard (1997), women have more sway (i.e., a measure of balance) than men at any given age. In support of this, Balogun et al. (1994) further found that men performed better on the one legged stance test than women at all ages after the first decade. Mean balance scores from the current study also show this although the differences were small and insignificant.

Grip strength There are a number of studies which have investigated the relationship between grip strength and aging. Together, they quite convincingly show that grip strength decreases as age increases. Van Heuvelen et al. (1998) and Rudsill and Toole (1994) both found an age effect in subjects over the age of 50. Kallman et al. (1990) used a much broader sample by looking at 847 healthy volunteers aged between 20 and 100 years. The authors found that although grip strength correlated strongly with muscle mass, it correlated even more strongly with age. Rantanen et al. (1998) and Bassey and Harries (1993) used grip strength in longitudinal studies to look at physical performance changes over time. Using a sample of 3680 men over the age of 27, Rantanen found that not only did the younger subjects have greater grip strength than older, but also that individual subjects significantly decreased grip strength scores over a period of 7 years. Bassey and Harries (1993) found similar results over a period of 4 years using a random sample of men and women over the age of 65.

Past studies have consistently found men to have stronger grip strength than women. Samson et al. (2000) found lower strength in women compared to men aged between 20 and 90 years. Similar results were found by Van Heuvelen et al. (1998), Rudsill and Toole (1994) and Desrosiers et al. (1995). The current study supports these findings.

Chair stand Rikli and Jones (1999b) found the chair stand test showed performance declines with age in a group of 60 community-living adults aged 60 and over. Although this sample does not extend to the ages of our younger group, due to the physiological changes that occur with aging, one would expect this trend to continue beyond the age group tested. Jones et al. (1999), similarly, found chair stand scores significantly decreased across each decade for subjects between the ages of 66 and 97. Cuska and McCarty (1985) tested 139 healthy men and women aged 20 to 85 years using a similar test whereby subjects were scored on the time they took to stand 10 times from a standard chair. They also found a performance decrease with age.

The current study did not reveal performance differences between men and women. Similarly, Miotto et al. (1999) did not find a gender effect using the same protocol with a sample of older adults aged 60 and over. The Cuska and McCarty (1985) protocol showed a significant gender effect in young subjects but not older.

Chair sit-and-reach The chair sit-and-reach test was devised as an alternative to the traditional floor sit-and-reach test to avoid the difficulties often encountered by older populations in getting up and down from the floor position (Rikli and Jones, 2001). As yet, this test has only been used in a few research studies. Jones et al. (1998) found the chair sit-and-reach to be a valid and reliable alternative to the floor sit-and-reach. A study by Rikli and Jones (1999b) using the chair sit-and-reach found performance declined with age in subjects aged 60 years and over.

Using the floor sit-and-reach test, Brown and Miller (1998) found flexibility declined with age in women between 20 and 70 years of age. The sharpest decline occurred in subjects in their 70's. Similarly, Payne et al. (2000) found mean scores for the sit-and-reach decreased with age in 571 men and women aged 15 to 69 years. According to Payne, these results were similar to those found in the Canada Fitness Survey of 1981 and the Campbell's survey of 1988 (Payne et al., 2000). The American College of Sports Medicine (1998) notes that the decline in flexibility with age begins earlier for men than women.

Considering the findings of previous studies, it is surprising that no age effect was found in the current study. Although mean scores were lower for older subjects as compared to younger subjects, these differences were not large enough to be statistically significant.

Results from this study showed a significant sex effect with women scoring better than men in both age groups. Miotto et al. (1999) found women scored higher than men on the floor sit-and-reach in a group of older adults ranging from 60 to 86 years of age. Payne et al. (2000) found this difference occurred for each decade in subjects aged 15 to 69.

Back scratch The back scratch test is used in the Senior Fitness Test to assess flexibility of the upper body - particularly of the shoulder (Rikli and Jones, 2001). Rikli and Jones (1999b) found an age decline in the performance of the back scratch test in adults aged 60 years and over. Phillips et al. (1987), similarly, found a decrease with age. Recent studies regarding shoulder flexibility and aging do not appear to use the back scratch protocol. In a group of 280 subjects ranging in age from 4 to 70 years, Barnes et al. (2001) found shoulder range of motion decreased with age in all motions except for internal rotation. Van Heuvelen et al. (1998) also found a low but significant correlation between shoulder flexibility and age. Somewhat in contrast, a longitudinal study of subjects aged 65 and older found loss of shoulder range of motion to be negligible (Bassey,1998).

Miotto et al. (1999) and Phillips et al. (1987) both found women demonstrated greater shoulder flexibility than men when performing the back scratch test. Differences were not significant in the current study. Using a different testing method, Barnes et al. (2001) also found women had a significantly greater range of motion than men.

8-foot up and go The 8-foot up and go test is a modified form of the more commonly used 3 metre version of the test. Modifications were made to enable the test to be performed in limited spaces (Rikli and Jones, 2001). Rikli and Jones (1999b) found the results for the 8-foot up and go test had a significant age effect in their study of community-living adults aged 60 and over. Steffen et al. (2002) similarly found a tendency for performance times of a 3 meter timed up and go test to increase with age in a sample of community dwelling subjects aged 61 to 89 years as did Samson et al. (2000) using a sample of 155 men and women aged 20 to 90 years. Using a similar, but much longer test (i.e., a 50 foot walk-turn-walk test), Kwon et al. (2001) also found a significant age effect with walking speed decreasing with each increasing decade of age in a sample of male and female subjects aged between 21 and 89 years of age.

Both Kwon et al. (2001) and Samson et al. (2000) found that women took longer to complete the test than men. No gender effect was found in the current study. The shorter distance may have contributed to this result.

Reaction time Results from the reaction time test used in the study found a significant age effect with younger subjects responding more quickly than older subjects. The protocol for the reaction time test was taken from the Older Driver Skill Assessment and Resource Guide produced by the American Association of Retired Persons (1998). A similar test also found older adults spent more time searching for numbers overlayed on a traffic scene as compared to the younger subjects (Maltz and Shinar, 1999). This reaction time test has similarities to the 'Trail Making Test (Part A)' in which subjects are required to connect a series of 25 numbers in consecutive order as quickly as possible. A number of cognitive processes are involved in performing the Trail Making Test making it a valid indicator of various forms of brain damage (Reitan, 1955). The skills required for completing such a test are somewhat beyond the needs of this study - although pertinent to the overall driving study. It is possible that a reaction time test more specific to ankle movement may demonstrate a relationship with isokinetic measurements such as RTD. Thelen el al. (1996) and Anstey et al. (1997) both used reaction time tests which require a physical reaction involving the ankle in response to a light stimulus - which may be more appropriate to this particular study. In Anstey's study, subjects were required to use their dominant foot to depress a switch. Thelen et al. (1996) measured reaction time as the time delay between the light stimulus and the onset of ankle torque development for isometric maximal voluntary contractions for both DF and PF. Both studies found reaction time slowed with age.

Conclusions regarding gender differences in reaction time are difficult to make. Using the test previously described, Thelen et al. (1996) found women had slower reaction times than men. Using an auditory reaction time test, Fozard et al. (1994) also found males were faster. Lee et al. (2003) found no gender difference in the time taken to react to a visual stimulus during sustained driving. It is clear that there is a great deal of variation in the protocols used to test reaction time. Reaction time is a complex term encompassing a wide variety of skills and behaviours. Although age declines in reaction time seem strong enough to be evident despite variation in test protocols, it appears the differences between genders are more subtle so that gender comparisons need to made within the context of the specific test.

In general, results for the field tests are in line with previous research. An age effect is apparent in this and other research studies whereby younger subjects tend to perform better than older subjects in all field tests. Sex differences do not appear to have been as thoroughly investigated as age differences in most of the field tests chosen for this study. Consequently, it is difficult to comment on performance differences due to sex in most cases. Grip strength, sit-and-reach and shoulder flexibility are the exceptions with previous research showing that men demonstrate greater strength than women and that women demonstrate greater shoulder and lower body flexibility than men. The current study found the same sex effect for grip strength and chair sit-and-reach but, in the case of the back scratch test, differences between men and women were not significant.

Generalizations made from the results of this study are limited, as are many studies, by the size and nature of the subject sample used. While there is always a question as to how representative a sample is of the population being studied, Shephard (1997) suggests this can be even more of a concern when studying older populations. Shephard (1997) reports that volunteer samples for studies related to older adults and physical activity may include a disproportionate number of individuals with an above-average level of fitness. Those who volunteer also tend to have adopted healthy lifestyle habits and are likely to have had less exposure to environmental pollutants (Shephard, 1997). In the current study the effect of these is somewhat lessened by the fact that subjects were predominantly volunteering for a driving study. However, there is a further consideration regarding the influence of the different environments into which each of the two groups were born. It is likely that advancing technology and knowledge gave the younger subjects an advantage of such things as better nutrition, improved medical treatment and less pollutants. Consequently, there is always a question as to whether differences between young and older groups is a direct result of aging or of a more complex combination of factors.

Despite the relatively low number of older individuals who participated in this study, results are convincing enough to warrant further investigation. A future replication of this study, using a much larger sample, would be expected to confirm the relationship between isokinetic tests and field tests as well as enable an equation to be formulated to predict ankle PT and RTD from a combination of field tests and physical measurements. Such a study could be downsized to include only those tests which have already proved to have a significant relationship with the isokinetic measurements i.e., grip strength, chair stand, and 8-foot up and go. Reaction time did not show a significant relationship with RTD in this study, but that may have been due to the particular test used. It is possible a reaction time test involving the ankle may have shown a stronger relationship to RTD.

Interpretation of passive stiffness results was limited by a significant amount of excluded data due to voluntary muscle involvement during testing. It is recommended that future passive stiffness studies use some form of biofeedback during testing to help subjects to perform the test correctly and, thus, obtain useable data. It may also be useful, in future studies on ankle stiffness, to compare passive stiffness results to a field test that is specific to the ankle joint.

CONCLUSION

This research suggests that the grip strength, chair stand, and 8-foot up and go tests can be used together to provide a good indication of an older individual's ankle strength and RTD. These field tests are easy to administer, and require very little time and equipment. This may prove useful to future aging research by providing a simple means of assessing changes in ankle function in order to investigate its influence on the deterioration of functional ability of older adults.

None of the field tests used in this study proved to be good indicators of passive stiffness in older adults. It is possible that a field test more specific to the ankle may demonstrate a stronger relationship to ankle passive stiffness.

Although the majority of PT and RTD results did not show a statistical age difference, there was a trend for younger subjects to score higher than older subjects. This was not the case for PS. However, similar levels of PS between older and younger subjects is not out of line with other studies. Results from this study supported the existence of a sex effect in isokinetic measurements with men having higher scores than women for PT, RTD and PS.

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APPENDIX A

Summary of Project

Muscles, joints and the nervous system are all importantly involved in driving a motor vehicle. The purpose of this study is to measure some aspects of the neuromuscular system along with driving behaviour in middle-aged and older adults. Neuromuscular testing will be done in a laboratory and driving will be assessed by you driving your own vehicle in a parking lot as well as on roads in and around Winnipeg.

Prior to conducting the driving or laboratory tests we will ask you several questions about your driving habits and your health. Several questions will be asked over the phone prior to scheduling an appointment in order to avoid you having to make a special trip to the University. Copies of these questionnaires have been attached.

I. Laboratory testing will be done in the **Neuromuscular Laboratory** (207 Max Bell Centre) at the Health, Leisure and Human Performance Research Institute at the University of Manitoba. These tests include tests of reaction time, strength, stiffness, mobility and balance. The order in which these tests are performed will be varied between subjects. Prior to any laboratory testing your resting heart rate and blood pressure will be measured to ensure that they are both at safe levels. In total the testing in the laboratory will last about 2 hours. Details are listed below for each test:

A. **Reaction time** will be assessed by viewing a driving scene on a piece of paper. You will point with your finger to specific places on the scene, as quickly as possible. This test lasts for 10 seconds.

B. A warm up of your muscles and joints will be performed by having you walk at a slow comfortable speed on a treadmill for 3 minutes.

C. The **stiffness** of the ankle will be measured by a device called a Biodex isokinetic dynamometer. You will be seated with your right knee elevated and your foot attached to a metal plate by a velcro strap. Your upper body will be stabilized to prevent unnecessary movement of the trunk. The Biodex will move your ankle through a comfortable range of movement, while you are totally relaxing your muscles. This movement will last approximately one minute. More than one trial may be performed to ensure that your muscles are totally relaxed.

D. The **strength** of the muscles around the ankle of the right leg will be

measured with the same machine and position as for the stiffness test. You will perform several contractions to familiarize yourself with the equipment and warm up. The contractions will involve pulling your foot towards your shin as well as pushing away with the ball of your foot. When you are ready you will perform contractions to your maximum ability, as fast and hard as possible. During these contractions you should not hold your breath.
Strength of the forearms will be assessed by using a small device that you hold in your hand. You will squeeze as hard as possible two times with each hand. Again you should not hold your breath while doing this test.

E. Sitting in a standard office chair with your foot fully on the floor you will perform as many **foot taps** as possible in 10 seconds, with your heel remaining on the floor.

F. Balance will be measured by standing with your eyes open and closed with one or two legs.

G. Mobility will be assessed by the Up and Go test, where you will start from a seated position, get up and walk 8 feet, and return and sit down.

H. Endurance will be measured by walking for 6 minutes. You will walk on a track in the Max Bell Centre, the same building as the Neuromuscular Laboratory. We will measure the distance you are able to walk in this time.

I. The maximum number of chair stands that you can perform in 30 seconds will also be done to assess mobility.

J. Flexibility of the leg will be assessed by the chair sit-and-reach. From a seated position and your right leg straightened in front of you, you will reach as far as possible towards your toes without bouncing. Flexibility of the shoulders will be assessed by you trying to touch your fingers together with one elbow above your shoulder and one elbow below.

II. **Driving tests** will be done at the University of Manitoba as well as on Winnipeg roads, starting from the University of Manitoba. The first test will involve driving around a parking lot (U Lot) at the Fort Garry Campus. This is not an obstacle course.

In both of the above situations, a small GPS receiver will be used to collect data (position, velocity and acceleration of your vehicle while you are driving). The receiver is roughly the same size as a camera, and will be positioned on the passenger seat or the back seat. A small magnetic antenna will be placed on the roof of the car, and attached through the passenger window to the GPS receiver.

The first driving course, in the parking lot, is roughly elliptical in shape, with four stop signs located at the half-way point and the end of each straight-away section. From the starting point you will drive your car several times around the course in a counter-clockwise direction, stopping at the stop signs, and following the course.

The second course will be on roads in and around the city of Winnipeg, and is depicted in the attached map and road description. You will be asked to drive as you would normally drive on these types of roads. The course includes city streets, Pembina Highway, and the Perimeter Highway. For this portion of the testing a video camera will be mounted on the passenger window to observe the drive from the perspective of a passenger. It will be set up so that there are no obstructions to your view. From the video tape and the GPS data we will be able to assess your driving behaviours.

You will be paid $10 to compensate you for gas consumed during the driving courses done.

Confidentiality

All experimental data associated with you will be identified with a subject number only. All subject files will be kept in a locked filing cabinet. In any written reports you will not be identified.

Benefits

There will be no direct benefit to you from these procedures beyond learning about your strength and physical performance. However, the investigators will learn about the driving performance of drivers across the lifespan. Also, you will be given the opportunity to learn more about GPS.

Risks

Laboratory Tests

There are risks associated with any type of physical activity. We have tried to minimize risks to you by asking you questions about your health status. You will also be highly supervised by trained individuals.

The likelihood of severe injury from this type of testing is very low. Typically exercise-related events that occur during testing of this nature include exacerbations of a pre-existing hernia and underlying arthritis or other joint abnormalities. Subjects will be screened for any kind of joint abnormality or other condition which could be exacerbated by testing. Even though the risk of severe injury other than temporary muscle soreness is very low, there is a theoretical possibility that a tear in a muscle or tendon could occur as a result of this type of testing. If there is any pain at any time during the testing, the test will be discontinued.

There is also the remote possibility of a cardiovascular incident (e.g., heart attack) during testing. In order to minimize cardiovascular events, all subjects will be screened for cardiovascular conditions such as recent or previous heart attacks or strokes, and other cardiovascular risk factors. To minimize the increase in blood pressure which can occur with straining, subjects will be instructed to breathe out while being tested.

Driving Tests

Through the course of the experiments you will be in no more danger than during a typical driving experience. The equipment will in no way affect your ability to drive. We will attempt to make sure that all driving will be performed on dry roads, and you will be asked to drive as you would normally.

There is a slight possibility that the magnetic antenna could slide on the roof of the car, potentially scratching the surface. The magnet is very strong and has been tested at speeds over 100 km/hr without any movement.

APPENDIX B

Consent Form

I understand the nature of the study including the potential risks and benefits. I have talked to Michelle Porter and/or her colleagues about this study, and my questions have been answered. If I have any other questions I may call:

Michelle Porter, University of Manitoba	474-8795
Satoru Nakagawa, University of Manitoba	474-7085
Bronwyn Zalewski, University of Manitoba	474-7085

This study has been approved by the Education / Nursing Research Ethics Board, and any complaint regarding a procedure may be reported to the Human Ethics Secretariat (474-7122).

I verify that my health allows me to drive, and I am not currently taking any medications that affect my driving ability.

I agree to participate in this study, but understand that I may withdraw at any time without prejudice and/or refrain from answering whatever questions you prefer to omit, without prejudice or consequence.

Name (print):________________________________

Signature: ________________________________ Date: __________

Investigator (print):________________________________

Investigator:________________________________ Date: __________

APPENDIX C

PAR-Q

Physical Activity Readiness Questionnaire

- Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

Yes _____ No _____

Comments:

- Do you feel pain in your chest when you do physical activity?

Yes _____ No _____

Comments:

- In the past month, have you had chest pain when you were not doing physical activity?

Yes _____ No _____

Comments:

- Do you lose your balance because of dizziness or do you ever lose consciousness?

Yes ____ No ____

Comments:

- Do you have a bone or joint problem that could be made worse by a change in your physical activity?

Yes ____ No ____

Comments:

- Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

Yes ____ No ____

Comments:

- Do you know of any other reason why you should not do physical activity?

Yes ____ No ____

Comments:

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

Name ______________________________

Signature __________________________ Date____________

Witness ____________________________

APPENDIX D

Driver Self-Rating Form

	Instructions: *For each of the following 15 questions, check which applies (always, sometimes, never or almost never*	*Always*	*Some-times*	*Never or Almost Never*
1	I signal and check to the rear when I change lanes.			
2	I wear a seat belt.			
3	I try to stay informed on changes in driving and highway regulations.			
4	Intersections bother me because there is so much to watch from all directions.			
5	I find it difficult to decide when to join traffic on a busy highway.			
6	I think I am slower than I used to be in reacting to dangerous driving situations.			
7	When I am really upset, I show it in my driving.			
8	My thoughts wander when I am driving.			
9	Traffic situations make me angry.			
10	I get regular eye checks to keep my vision at its sharpest.			
11	I check with my doctor or pharmacist about the effect of my medications on driving ability (If you do not take any medication, skip this question)			

12	I try to stay abreast of current information on health practices and habits			
13	My children, other family members or friends are concerned about my driving ability.			
	New headings	*None*	*1 or 2*	*3 or more*
14	How many traffic tickets, warnings or "discussions" with officers have you had in the past two years?			
15	How many accidents have you had during the past two years?			

APPENDIX E

Physical Activity Questionnaire
Interview Questions

Subject ID # ________________ Date: ________________

What types of physical activities have you been involved in during the last couple of months?

How long each time for each activity, on average?

How often, on average?

At what kind of intensity?

Grimby Scale Rating __________

APPENDIX F

Reaction Time Test

TEST STEPS

- **Find the number 1 in the upper left corner of the picture. Start the timer for 10 seconds.**
- **Then as quickly as you can, touch the other numbers in numerical order (2,3,4,5,6,7, etc.).**
- **Stop after 10 seconds. Make a note of the last number you touched. This is your score.**

Imagine you are driving through town. Traffic is heavy. A delivery van suddenly pulls right out in front of you. You must react quickly to avoid an accident. Is there enough room? Can you change lanes safely? Is there something in front of the van, perhaps a pedestrian or an animal crossing the street?

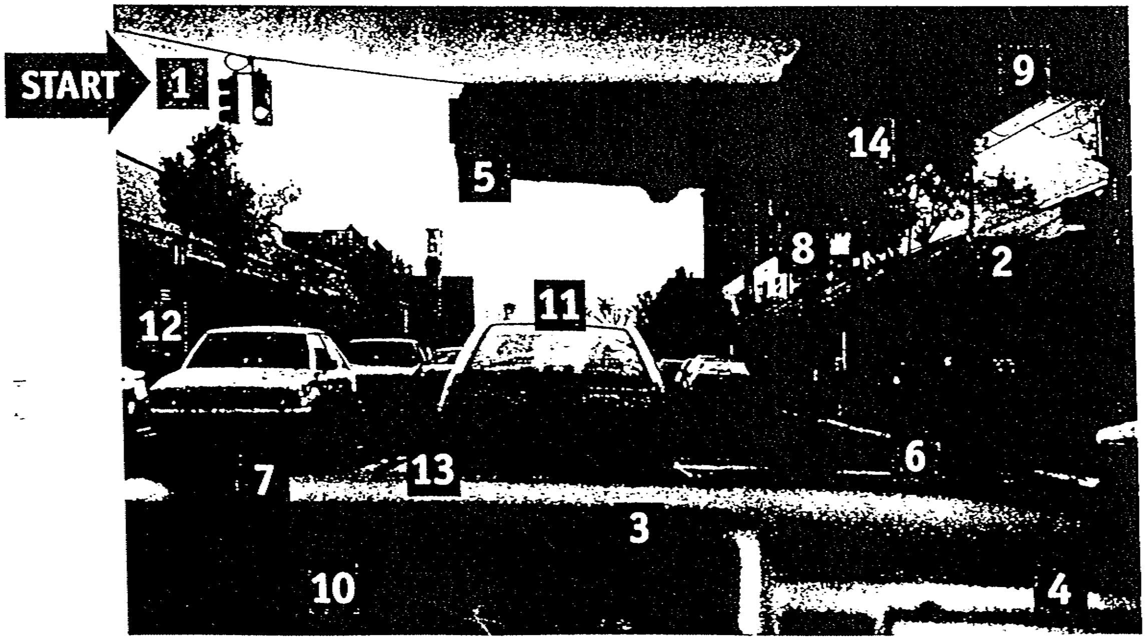
This is just one example of the many times when you have to react quickly while driving. Yet our ability to do so slows as we grow older. We have to work harder at anticipating trouble.

This easy test takes only a few minutes and will help you measure your reaction time. You will need to be timed, so it may be easier to get a friend or family member to help.

Directly below is a photograph of a typical driving scene. Notice a series of numbers (1-14) overlaid on the photo. The object of the test is to find and touch each of these numbers in numerical order within 10 seconds.

Practice the test first; then take it again to find your score.

Compare your score on the chart on the following page.



APPENDIX G

Test Reliability

Bronwyn Zalewski

Department of Physical Education and Recreation Studies
University of Manitoba
Winnipeg

INTRODUCTION

Physical ability testing is commonly used to assess the capabilities and limitations of various populations including the injured, disabled, sporting elite and older adults. Testing may take place in either a laboratory or field setting. Laboratory tests usually involve the use of sophisticated equipment in a controlled environment which allows for precision measurements. In comparison, field tests are typically simple to administer and require relatively inexpensive equipment which is generally portable. These attributes reduce the limitations of equipment cost and technician availability associated with laboratory testing enabling testing to be performed more readily and on larger samples.

Regardless of whether testing takes place in a field or laboratory setting, the test needs to provide reliable results in order to be meaningful. The term 'reliability' has been defined as "the consistency of results" (Safrit and Wood, 1995, p. 169), or similarly, "the degree to which test scores are consistent, dependable, or repeatable," (American Psychological Association, 1985, p.93). A reliable test has ultimately eliminated all possible errors that could be associated with the scoring procedure thus providing consistent results. Consequently, one would expect a reliable test to give similar results when administered on separate occasions assuming no intervention, maturation, or other occurrence that may affect test performance has taken place between trials. This can be referred to as intrarater, inter-test, or test-retest reliability.

The purpose of this study is to investigate the test-retest reliability of three field tests - foot tapping speed, balance and reaction time. These tests were chosen due to their planned use in an upcoming research project. Because all three tests have been previously used in published research studies (Kent-Braun and Ng, 1999; Gill et al, 2001; American Association of Retired Persons, 1998), one would assume these tests have proven reliability. It is therefore hypothesized that foot tapping speed, balance and reaction time tests will demonstrate strong test-retest reliability.

METHODS

Subjects

Subjects consisted of 20 volunteers (15 female; 5 male) ranging in age from 23 to 50 years. All subjects were screened prior to their participation by using a Physical Activity Readiness Questionnaire. Those who suffered injuries or health conditions that could affect test results or endanger their health were excluded from participation. An informed consent was completed by all subjects prior to testing.

Subjects participated in two testing sessions 2-5 days apart. Test sessions consisted of foot-tapping, balance, and reaction-time tasks. Testing took place in a location convenient to each subject ensuring suitable space and minimal distractions (e.g., noise, other people, time constraints) existed. The same tester performed all tests. Apart from the completion of the PAR-Q and consent forms, both test sessions were the same. Practising between sessions was discouraged.

Protocols

Foot tapping

The subject was seated with hip and knee angles of approximately 90^0. A stable, straight-backed chair with no arm rests and a seat height of approximately 43cm (17 inches) was used. Feet were comfortably spaced and placed flat on the floor. Subjects tapped the ball of their right foot as many times as possible in a 10 second period while keeping their heel in contact with the floor. They were instructed to use a full range of motion as opposed to twitch-like movements. The number of taps completed was recorded. Tests were performed in bare or socked feet. Subjects were permitted 2-3 taps for familiarization.

Balance

Subjects performed 4 balance tasks for a maximum of 20 seconds each.
Task 1: two-legged stance, feet comfortably apart, eyes open.
Task 2: two-legged stance, feet comfortably apart, eyes closed.
Task 3: one-legged stance (balancing on right leg), eyes open.
Task 4: one-legged stance, (balancing on right leg), eyes closed.

The subject's performance of each task was timed using a stopwatch. Timing stopped immediately if the subject lost balance (i.e., supporting foot/feet moved or subject fell). If the 20 second maximum time was not achieved on the first attempt, a second attempt was made. The longest time achieved was recorded and used for analysis.

Arms hung by the subject's side for each task although they were allowed to move away from sides during tasks to assist with balance. Arms were not, however, permitted to rest against subject's body (e.g. 'hands on hips'). In one-legged tasks, subjects were asked to raise their left foot backwards from the ground. Timing commenced once the foot left the ground. In task 4, subjects first closed their eyes and then lifted their foot. As with the arms, the free foot was allowed to move to assist with balance, but was not permitted to be braced against the body.

Shoes were not worn during the performance of the balance tasks. Testing was conducted in an open area free of obstacles. A spotter was present to assist if necessary.

Reaction time

The protocol for the reaction time test was taken from the Older Driver Skill Assessment and Resource Guide produced by the American Association of Retired Persons (1998). The guide contains a picture of a driving situation which was presented to the subject. The picture is positioned on the lower half of a letter-sized page. The numbers one to fourteen are superimposed onto the picture in a random fashion.

Once the picture was presented, the subject attempted to find the number "1" and put their finger on it. Once this was achieved, they searched for the number "2" and put their finger on it. The subject continued this process trying to find each of the fifteen numbers in consecutive order.

Subjects were given 10 seconds to locate as many of the numbers as they could. The picture was kept face down until the test protocol had been explained and understood. A description of the approximate position of the first number is given to subjects prior to seeing the picture (i.e., 'top right hand corner'). Timing began as soon as the picture was turned face up. The last number the subject located and touched within the ten second time period was taken as their score.

Statistical Analysis

Several statistical calculations were used to compare scores:

- paired t-test
- Pearson product moment correlation
- intraclass correlation (ICC)
- standard error of measurement (SEM)

There are several methods of calculating ICC. For this study, $ICC_{2,1}$ was used (Holmbäck, 2002). The data was plotted using Bland-Altman graphs. In these graphs, the difference between test session results (i.e. session 1 minus session 2) is plotted against the mean for each subject. ICC was calculated using SPSS 11.0 for Windows (SPSS Inc., Chicago). All other calculations were performed with SigmaStat version 3.0 (SPSS Inc., Chicago). SigmaPlot version 8.0 (SPSS Inc., Chicago) was used to create the Bland-Altman graphs.

RESULTS

Means and standard deviations for foot tap, balance (task 4) and reaction time tests are presented in Table 1. Results from statistical calculations for foot tap and reaction time tests are presented in Table 2. Data from balance tests did not follow a normal distribution and so was not suitable for these calculations.

Table 1. *Means and standard deviations for foot tap, balance and reaction time tests*

	Foot Tap	**Balance (4)**	**Reaction Time**
Session 1	35.65 ± 5.12	15.56 ± 6.45	9.70 ± 2.32
Session 2	36.25 ± 5.47	15.98 ± 6.59	10.85 ± 2.58

Table 2. *Reliability measures for foot tapping and reaction time tests*

	t-test	**r**	**ICC**	**SEM**	**SEM%**
foot tap	not significant (p>.05)	0.93 (p<.001)	0.93	1.4	14.6%
reaction time	significant (p<.05)	0.64 (p<.001)	0.64	1.5	24.3%

Foot Tap

Statistical calculations showed good reliability for the foot tapping test. Paired t-testing of foot tapping scores found no statistical difference between the mean scores of sessions 1 and 2. Calculation of Pearson's correlation coefficient showed a strong relationship between scores achieved in both sessions. Similarly, the ICC showed excellent reliability according to the recommendations

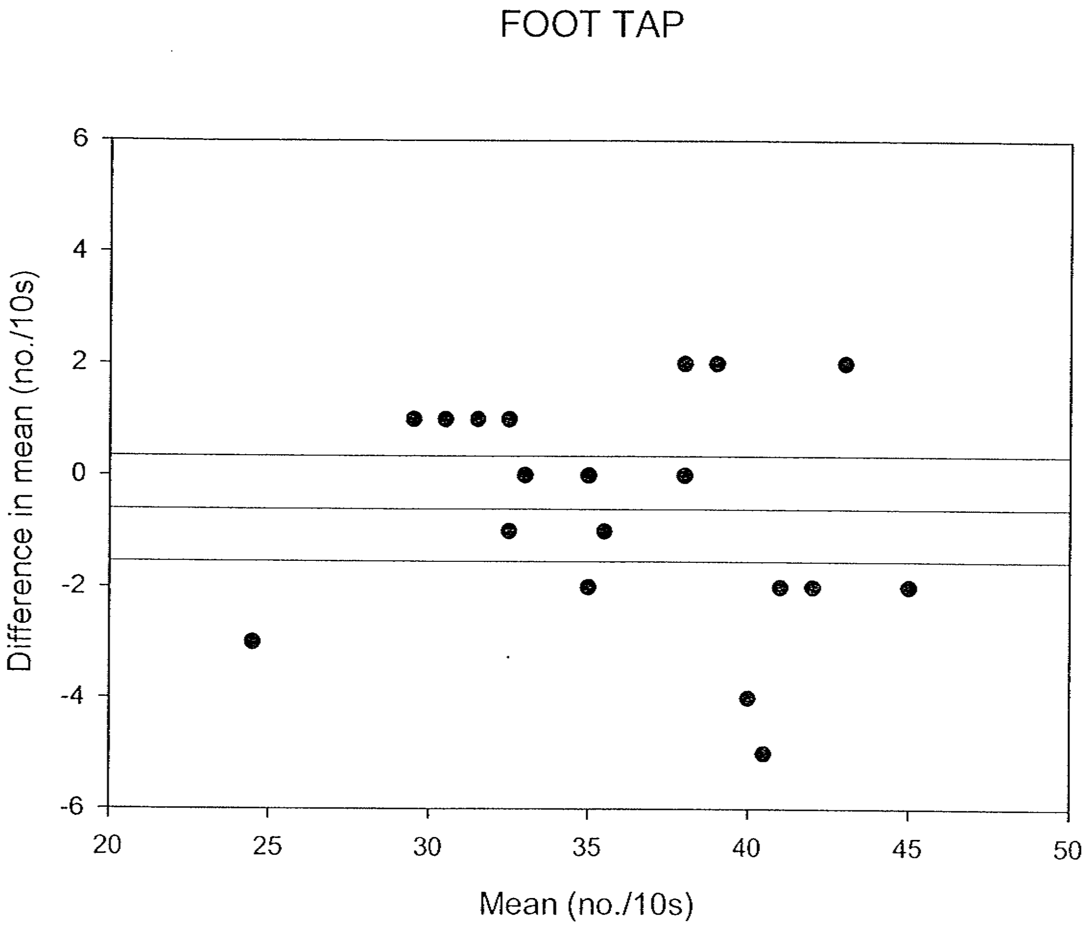


Figure 1. The difference in means between test sessions 1 and 2 plotted against their mean for foot tapping.

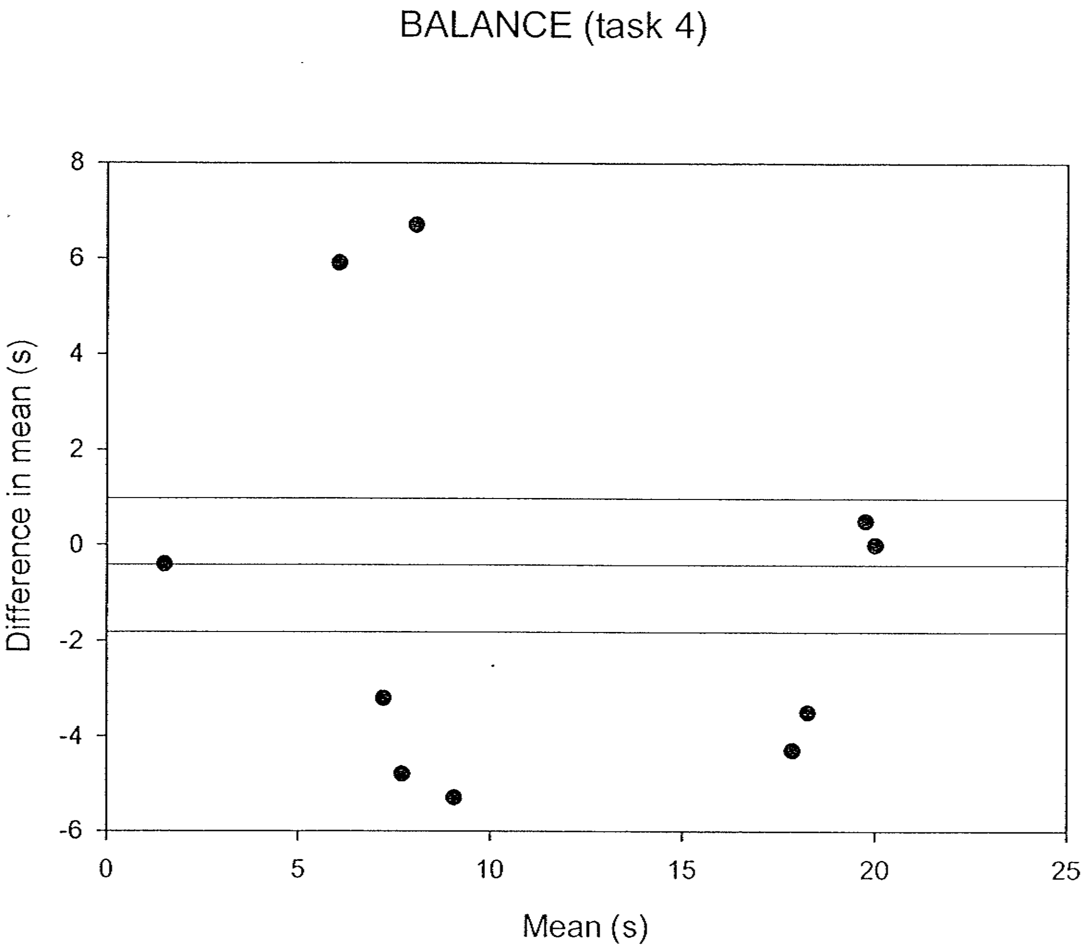


Figure 2. The difference in means between test sessions 1 and 2 plotted against their mean for balance task 4.

REACTION TIME

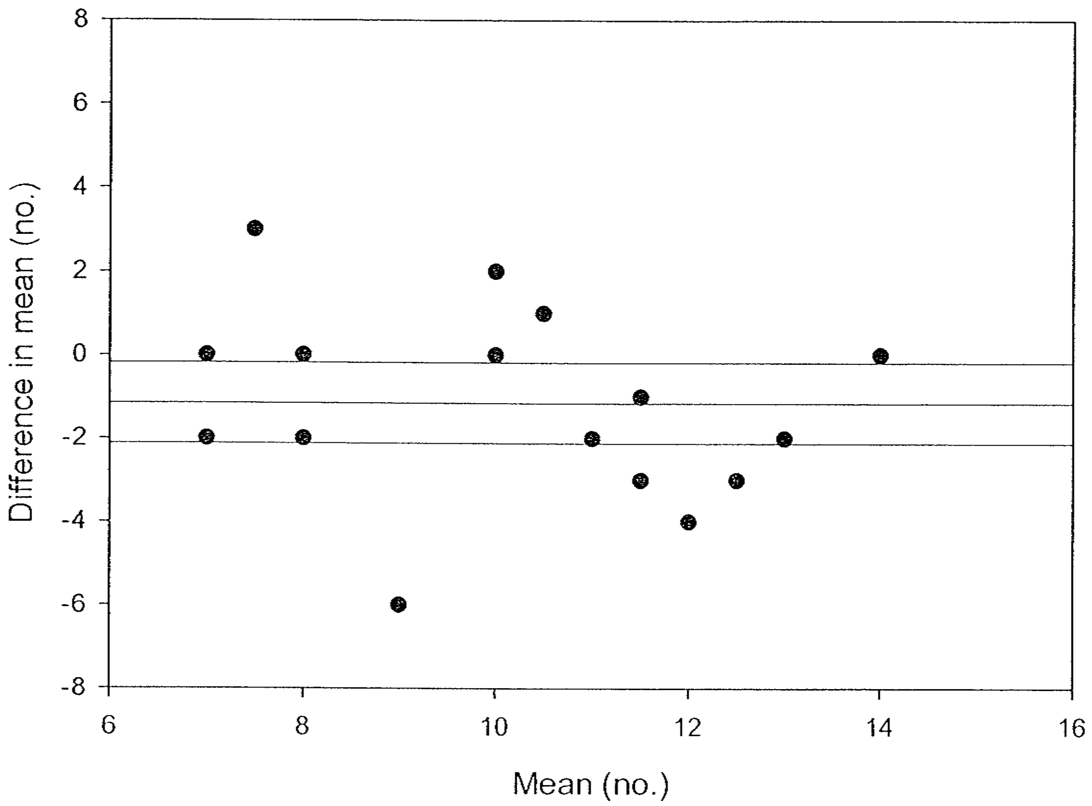


Figure 3. The difference in means between test sessions 1 and 2 plotted against their mean for reaction time.

made by Fleiss (1986). The zero line is included within the 95% confidence intervals on the Bland-Altman graph (Figure 1) indicating no significant systematic bias is present in data (Holmbäck et al., 2001). The SEM shows low within subject variation.

Balance

For the population sample tested in this study, the balance test demonstrated a strong ceiling effect with all subjects achieving the maximal score for tasks 1 and 2. The data for these particular tasks was not further analysed. Tasks 3 and 4 showed some variation although the data still did not follow a normal distribution. Consequently, the chosen statistical methods were not appropriate for analysing this data. Alternatively, a Mann-Whitney Rank Sum Test was performed. Results showed no statistical difference between test sessions for tasks 3 and 4.

Reaction Time

T-testing of reaction time scores showed a significant difference between testing sessions indicating poor reliability. In support of this, neither Pearson's r nor ICC suggest a strong relationship in the data. SEM was relatively high. The Bland-Altman graph (Figure 3) reveals some systematic bias in the data with the difference in the mean being below the zero line for the majority of subjects. This indicates a significant tendency for subjects to score higher in the second test session - most likely due to a learning effect.

DISCUSSION

Test-retest reliability studies commonly use Student's t-test or a correlation coefficient (particularly Pearson's r) to determine whether a test is, in fact, reliable. However, these methods have been criticized as being inappropriate and potentially misleading (Altman and Bland, 1983; Bland and Altman, 1986). It has been suggested that the ICC is a more suitable correlation coefficient than Pearson's r when testing for reliability (Holmbäck, 2002). However, correlation coefficients are limited to providing information about the relationship between sets of data (i.e., relative reliability). Holmbäck points out the need to also assess the within subject variation (i.e., absolute reliability) and to look for systematic changes that may be present in the data. Consequently, correlation calculations alone are not sufficient for reliability studies.

Altman and Bland (1983) further comment that scattergrams, which are often used to illustrate correlations, can also be misleading because a) much of the plot is empty space, and b) agreement between data will appear to be better as the range of scores increases. They prefer the use of what has become known as Bland-Altman graphs which plot the mean scores of the two testing sessions against the difference between the means (see figures 1-3 for examples) (Bland and Altman, 1986). This graph provides a means of recognising the degree of error and bias in the data as well as identifying any trends that may exist.

Outliers are also easily identifiable.

It is for the reasons outlined above that the statistical analysis for this study has included a paired t-test, ICC, Pearson's r, SEM and Bland-Altman graphs. These statistical methods were selected with the intention of providing a comprehensive presentation of the data.

Results from this study show good test-retest reliability for the foot tapping test only. The balance tests do not give suitable results on a continuous scale due the ceiling effect that was encountered. The Bland-Altman graph (Figure 2) reveals the abnormality of the balance data. Most striking is the lack of data points which is a result of 11 out of 20 subjects obtaining the maximum score of "20". The majority of the remaining subjects had a large degree of variability between their scores. So, although the Mann-Whitney Rank Sum Test found no significant difference in between sessions, this cannot be interpreted as a demonstration of good test-re-test reliability in this case. It is possible that the balance test may provide meaningful measurements on a continuous scale if performed on a subject sample with a low balance threshold. Gill et al. (2001) found a significant difference in the stance duration of older adults compared to middle-aged and younger adults in tasks 3 and 4 suggesting that the ceiling effect in these tasks was not so pronounced, and possibly not apparent, for older adults.

The reaction time test did not prove to have good test-retest reliability. When performed by this particular subject sample, a definite learning effect was apparent in the data. There were even anecdotal reports of subjects 'remembering' where certain number were positioned. The test was taken from the Older Driver Skill Assessment and Resource Guide (1998) where it is suggested that subjects have a practice trial immediately prior to their test trial. In the present study, the practice was excluded to avoid the effect of memory (i.e., learning) on test results. By including the practice trial it is possible that better reliability may have been achieved, however, the test would likely become more a performance of a learned task and less a test of reaction time. Perhaps a reliable test of reaction time reliability might be achieved with a slight change in the methodology whereby the numbers on the driving scene are rearranged for each trial.

It is recognised that there are some weaknesses in this study. Fleiss (1986) suggests 15 - 20 subjects is usually enough for reliability testing when using continuous data. However, in this instance, statistical tests for foot taping and reaction time had low power indicating more subjects are needed in order to be confident of results.

The subject sample was a sample of convenience which was made up of a haphazard selection of available people. It included work colleagues, family and friends. As both r and ICC are highly sensitive to spread of values between subjects (Holmbäck, 2002), the sample studied should be representative of the population to be studied. In other words, if we want to conclude that these tests are reliable when used on a population of older adults, for example, the reliability testing must be performed specifically on older adults.

In conclusion, this study showed good test-retest reliability for the foot tapping test. The reaction time test did not show good test-retest reliability for the subject sample used in this study. Data from the balance tests did not follow a normal distribution so was not suitable for analysis using the statistical methods chosen.

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