To the Graduate Council:

I am submitting herewith a dissertation written by June Elaine Hanks entitled "Diabetic Neuropathy, Balance, Falls and Fear." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy with a major in Education.

Wendell Liemohn, PhD, Major Professor

We have read this dissertation and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and
Dean of The Graduate School

DIABETIC NEUROPATHY, BALANCE, FALLS AND FEAR

A Dissertation
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June Elaine Hanks
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ABSTRACT

The results of previous studies indicate decreased static balance, less perceived safety and increased injurious falls among neuropathic diabetics. The objective of this study was to determine the relationship between diabetic neuropathy, dynamic balance performance, falls and fear of falling among a diabetic sample population. Fourteen neuropathic diabetics (DM-NP), non-neuropathic diabetics (DM) and controls were assessed on the Berg Balance Scale (BBS), Timed Up & Go (TUG), fall history and fear of falling.

The results of this study demonstrate significant differences on TUG and BBS performance between DM-NPs and controls, between DM-NPs and non-neuropathic participants and between diabetics and controls. There was a significant difference between DMs and controls on BBS performance. There was no significant difference on TUG and BBS performance between DM-NPs and DMs. Performance on BBS item 14 (single leg stance) was significantly different among all groups. Performance on TUG and BBS was not associated with number of reported falls and fall category (high and low fallers) among diabetics. Diabetics reporting two or more falls in the past year performed more poorly on BBS item 8 (stand and reach), item 12 (alternately placing foot on stool), and item 14 than diabetics reporting one or no falls in the past year. There was no association between fear of falling and diabetic neuropathy, fall history

and fall category. There was an association between fear and clinical balance performance.

The ability of BBS items to differentiate high and low fallers among diabetics may prove useful in identifying diabetics at risk for falls. Studies of dynamic balance among diabetics should allow for the potentially confounding influence of fear of falling.

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CHAPTER I: INTRODUCTION

Peripheral neuropathy is a common complication of diabetes mellitus (Delbridge, Ctercteko, Fowler, Reeve, & LeQuesne, 1985). Diabetic neuropathy is clinically detectable in 25 percent of diabetics after 10 years of diagnosis and in up to 50% of diabetics within 20 years of diagnosis (Pirat, 1978). The most common form of diabetic neuropathy is distal symmetrical polyneuropathy that affects both motor and sensory function, but particularly the latter. Sensory deficits appear first in the distal-most part of the lower extremity and progress proximally. Large and small sensory fiber involvement leads to diminished pain, temperature, proprioception, light touch perception and vibration perception. Large motor fiber involvement results in lower leg and foot muscle weakness and imbalance between the long toe flexors and extensors, leading to increased plantar pressures during weight bearing (Ctercteko, Dhanendram, Hutton, & LeQuesne, 1981). The combination of insensitivity and increased plantar pressure is a cause of ulceration in diabetics (Levin, 1997), a complication commonly resulting in amputation (Reiber, 1993).

In addition to ulceration, diabetic neuropathy is associated with falls and postural instability. Diabetics with neuropathy are at greater risk of fall-related injury (Cavanagh, Derr, Ulbrecht, Maser, & Orchard, 1992) and demonstrate more postural sway during standing (Simoneau, Ulbrecht, Derr, Becker, & Cavanagh, 1994; Uccioli et al., 1995). Considerable research has been devoted

to the study of postural instability and predictors of fall risk in the well and frail elderly population (Campbell, Borrie & Spears, 1989; Duncan Wilson, MacLennan & Lewis, 1992); Duncan Studenski, Chandler & Prescott, 1992; Lord, Ward, Williams & Anstey, 1994). The purpose of this study is to add to existing information on postural instability among diabetics by investigating the relationships between diabetic neuropathy, functional balance performance, falls and fear of falling.

CHAPTER II: REVIEW OF THE LITERATURE

A. Mechanism of postural control

Balance is achieved through the synthesis of somatosensory, visual and vestibular information by higher brain centers. The muscle, joint and cutaneous receptors of the somatosensory system provide information to the central nervous system on joint position and movement (Simoneau, Ulbrecht, Derr, & Cavanagh, 1995). Vision provides information about the identity and movement of objects and signals the location and motion of the head in space. The vestibular system indicates head position and movement with respect to gravity (Shumway-Cook & Woollacott, 1995).

The relative influence of the afferent sensory systems on postural stability has been studied in non-diabetic subjects of various age and health status. An increase in postural sway has been demonstrated in healthy elders with visual and sensory deprivation not related to age (Ring, Nayak, & Isaacs, 1989). Duncan et al. (1992) found that vibration sense showed a consistent relationship to all measures of sway in men and a positive association which was not statistically significant in women. Older subjects (mean age 80 years) free of neurological disease exhibit significantly impaired balance performance with reductions in visual input and in distal lower extremity tactile and proprioceptive input (Judge, King, Whipple, Clive, & Wolfson, 1995). In a study of elderly

subjects, Brocklehurst, Robertson, and James-Groom (1982) found an association between postural sway and impaired vibration sense in the legs and no correlation between postural sway and visual deprivation. In a study of residents of a hostel for the aged, a reduction in visual input was associated with body sway when subjects stood on a compliant surface, but not when they stood on a firm surface, indicating a significant influence of ankle proprioception on sway (Lord, Clark, & Webster, 1991a). Teasdale, Stelmach, and Breunig (1991) studied young and older subjects and found sway was influenced more under altered visual conditions than under altered surface conditions, but was influenced most under combined altered visual and surface conditions.

The simultaneous involvement of vision and peripheral nerves in diabetes may predispose this population to balance problems and falls. The effect of diabetes on peripheral nerves may affect postural control, as sensory afferent input and motor efferent output is required (Geurts et al., 1992). Visual impairment, a common consequence of diabetes (Orchard, et al., 1990) may contribute to balance difficulties. Evidence of an association between diabetes and vestibular system function is limited and inconclusive (van Deursen & Simoneau, 1999). Although central nervous system involvement in diabetes is evident, the association between central processing and postural instability in diabetics with neuropathy has not been established (Uccioli, et al., 1997).

Dynamic posturography has been used to discriminate between the

relative effects of somatosensory, visual, and vestibular information in postural control in diabetics. Dynamic posturographic equipment consists of a moveable forceplate, a moveable visual surround and a computer for data analysis. The results of dynamic posturographic analyses indicate that vision and vestibular involvement may play a role in postural instability in neuropathic diabetics, but the proprioceptive involvement of the foot and ankle predominate as the primary source of balance disturbance (Nardo et al., 1999; Uccioli, et al., 1995; Uccoli, et al., 1997; van Deursen & Simoneau, 1999).

In normal individuals, the muscle spindles of the lower legs appear to play the major role in postural control (Hay, Bard & Fleury, 1996; Quoniam, Hay, Roll, & Harlay, 1995), whereas the relative importance of the various receptors to postural instability in neuropathic diabetics less clear (van Deursen & Simoneau, 1999). The perception of ankle movement in neuropathic diabetics is impaired, requiring greater ankle angular displacement for movement recognition (Simoneau, Ulbrecht, Derr, Becker & Cavanagh, 1996). Impaired muscle spindle function appears to play a role in reduced ankle movement perception, but the mechanism has not been clearly illuminated (van Deursen, Sanchez, Ulbrecht, & Cavanagh, 1998). Functional deficits in Golgi tendon organs and joint mechanoreceptors are assumed, but there is a lack of research to demonstrate specific involvement (van Deursen & Simoneau, 1999).

B. Neuropathy and gait

Though the mechanism is unclear, the effect of sensory neuropathy on balance and posture has received considerable research attention. Diabetics with peripheral neuropathy give a greater amount of attention to walking (Courtemanche, et al., 1996) and demonstrate a slower walking velocity and shorter stride length than controls (Mueller, Minor, Sahrmann, Schaaf, & Strube, 1994; Courtemanche, et al., 1996). It has been suggested that changes in walking characteristics may be compensatory strategies used by neuropathic persons to maintain upper body stability during dynamic gait (Courtemanche, et al., 1996). Unique gait characteristics may also be related to fear of falling. Maki (1997) reported that increased stride to stride variability is an independent predictor of falls in older ambulatory adults, but the stabilizing characteristics of slower walking speed, shorter stride length, and prolonged double support are related to fear of falling and are not independent predictors of falls.

C. Neuropathy and falls

Richardson, Ching, and Hurvitz (1992) reported that peripheral neuropathy is associated with falling. Cavanagh et al. (1992) noted that neuropathic diabetics are 15 times more likely to report injury during walking and standing and report less perceived safety in unusual situations than non-neuropathic diabetics of the same gender, duration of diabetes, and degree of

retinopathy. The authors suggest that the results may underestimate the effect of neuropathy on posture and gait, as interviewing methods were used to obtain data regarding falls and injuries.

D. Neuropathy and posturography

Static posturography is a technique in which a subject stands quietly on a force platform while the excursion of the center of pressure, a measure of postural sway, is calculated (Simoneau et al., 1994). Following stringent screening of participants to exclude influencing factors other than diabetic neuropathy, Simoneau, et al. (1994) studied controls and diabetics with and without neuropathy and reported that postural instability, evidenced by degree of postural sway on a force platform, was associated with sensory neuropathy. Neuropathic diabetics demonstrated a greater degradation of stability as visual inputs were compromised, suggesting that the neuropathic diabetics may have relied more heavily on visual inputs to compensate for loss of sensory inputs than the non-neuropathic diabetics and controls. However, in a multiple regression analysis of the sensory characteristics (vibration perception threshold, touch pressure sensation) and physical characteristics (age, weight, height, duration of diabetes, retinopathy, vision, ankle strength, and range of motion), only sensory neuropathy and age contributed significantly to the instability observed.

Dynamic posturography has been used to study the balance response to postural perturbations in diabetics with neuropathy and in control subjects. Each subject stood on a moveable platform and the response to translational and rotational perturbation was analyzed. Neuropathic diabetics demonstrated the normal pattern of response in which distal muscles were activated prior to proximal muscles, but the response was delayed and of larger amplitude than in the control subjects. It was proposed that the increased amplitude of response in neuropathic subjects may be a protective mechanism to avoid falling (Inglis, Horak, Shurpert, Jones-Rycewicz, 1994).

E. Functional balance assessment

The tasks of maintaining balance control during quiet stance and during dynamic activity, such as walking, differ significantly. In stance, the center of mass (COM) must be maintained within a stationary base of support (BOS). In walking, the COM and BOS are both moving and the COM is not maintained within the BOS during single-limb support (Winter, 1995). In order to fully assess balance control, stability in movement should be examined. Common clinical functional balance performance tests include the Berg Balance Scale (BBS), Dynamic Gait Index (DGI), Balance Self-Perceptions Test (BSPT), Functional Stand and Reach (FSR), the Tinetti Balance and Gait Score (TBGS), and the Timed Up and Go (TUG) test.

Although no "gold standard" exists for assessing balance, the reliability and concurrent validity of the BBS with other clinical measures of balance has been demonstrated. The inter-rater and intra-rater reliability of the BBS is high (both ICCs = 0.98) and BBS scores correlate strongly (r = 0.81) with overall balance ratings by therapists treating the subjects (Berg, Wood-Dauphinee, Williams, & Gayton,, 1989). The correlation of the BBS with Tinetti's Balance Sub-scale and the Timed Up and Go is 0.91 and – 0.76, respectively (Berg, Wood-Dauphinee, Williams, & Maki,1992).

The DGI is used to rate performance on different gait tasks including stepping, pivoting, and turning and has demonstrated good reliability (Shumway-Cook, Gruber, Baldwin, & Liao, 1997) and high correlatation with risk factors for falls and with other tests (Shumway-Cook, Baldwin, Polissar, & Gruber, 1997). The TUG has been shown to have high inter-rater and intra-rater reliability (both ICCs = 0.99) and to correlate well with the BBS and other gait and balance scores (Podsiadlo & Richardson, 1991). The reliability of the TBGS has been demonstrated (Tinetti, 1986) and is useful in identifying elderly persons at risk of falling (Tinetti, Speechley, & Ginter, 1988). These commonly used clinical balance measures have not been routinely employed in studies of balance performance in neuropathic diabetics.

In a study of community dwelling elderly with and without diabetes, there was no difference between groups on TUG test (Braun et al., 1996). No

objective measure of neuropathy was obtained and the subjective sensation of numbness/poor feeling in the feet was reported in only 18% of the diabetics in the study.

F. Balance and falls

Conflicting results have been reported in studies of the relationship between postural sway and falls. In retrospective studies, some researchers have found a correlation between sway and fall history (Lichtenstein , Shields, Shiavi, & Burger, 1988; Overstall, Exton-Smith, Imms, Johnson, 1977; Overstall, Johnson, Exton-Smith, 1978; Imms, Edholm, 1981; Brocklehurst et al., 1982), whereas others have not (Fife & Baloh, 1993; Baloh et al., 1994). In a study of institutionalized elderly, the mean speed of sway was significantly greater for those who fell one or more times than for those who did not fall. Yet, there was no association between increasing mean speed of sway and increasing fall frequency (Fernie, Gryfe, Holliday, & Llewellyn, 1982). A prospective study by Lord et al. (1994) on elderly women 341 women [ages 73.6 ($\pm$ 6.3)] sought to determine physiological factors associated with falls in a one year time period. Results indicated that multiple falling was associated with vision, decreased vibration sense (determined by a vibration device applied to the tibial tuberosity), poor leg strength, decreased reaction time and impaired balance

(assessed by static sway and ability to march in place for one minute with eyes closed).

Risk factors for multiple falls among the elderly include the following: previous falls, previous injurious falls, poor tandem gait, decreased vision, neurological disease, cognitive impairment, use of sedatives, lower extremity disabilities, gait abnormalities and balance disturbance (Nevitt et al, 1989; Tinetti & Speechley, 1990). Several researchers agree that past history of falls (Harada, Chiu, & Damron-Rodriquez, 1995; Nevitt et al, 1989; Studenski et al., 1994) and decreased balance and mobility (Studenski et al., 1994; Tinetti & Speechley, 1988) are strong predictors of the likelihood of falls.

In a study of residents in a home for the elderly, Berg et al. (1992) reported predictors of falls to include balance scores (BBS), vision and previous falls, though no one factor or individual characteristic was responsible for falls. Based on clinical experience indicating a BBS score of 45 to be a cut-off point below which supervision or assistance during walking may be required, Berg et al (1992) studied the fall risk among residents in a home for the elderly and reported a relative risk of 2.7 falls over a 12 month period for individuals with BBS scores less than 45.

A study by Thorbahn and Newton (1996) of elderly persons living in independent life-care facilities demonstrated the Berg to be highly specific (96%), correctly identifying persons scoring ≥ 45 as having a high probability of

not falling. The Berg demonstrated low sensitivity, accurately predicting those who would fall 53% of the time. The authors interpreted the low sensitivity result as indicating the multi-factorial nature of fall risk. The most frequent fallers scored closer to the cutoff score of 45 rather than further away. Participants most physically impaired may be less likely to fall due to the adoption of compensatory strategies, such as the use of assistive devices.

In a study to develop a model of fall risk among community-dwelling older adults, factors considered were age, gender, medications, mental status, use of assistive devices, BBS, DGI, score on the BSPT, speed of self-paced and fast-paced gait, and history of imbalance. Factors identified as the most sensitive and specific to fall risk among community-dwelling older adults were the BBS and a self reported history of imbalance (Shumway-Cook, Baldwin, et al., 1997).

In a retrospective study of elderly participants independent in activities of daily living, Maki et al. (1991) reported poorer scores on the Tinetti balance test among participants who reported having fallen one or more times in the previous year. There was no association between fall history and postural sway or single leg stance. Results indicated that the better predictor of single leg stance performance was fear of falling, rather than fall history.

In studies of elderly community dwellers, an association between multiple falls and fear of falling has been demonstrated (Tinetti et al., 1988;

Vellas, Wayne, Romero, Baumgartner, & Garry, 1997). Among the study participants who had fallen in the previous year, 48% were afraid of falling and 28% limited their activities because of fear of falling (Tinetti, et al., 1988). The likelihood of reporting fear of falling was greater among women (Vellas et al., 1997).

G. Static and functional balance tests

The clinical value of postural sway measures remains unclear. In a study of residential elderly subjects, a moderate correlation (range -0.46 to -0.67, average -0.55; $p < .01$) was demonstrated between the BBS and spontaneous sway tests of varying amplitudes and speeds (Berg, Maki, Williams, Holliday, & Wood-Dauphinee, 1992). In a study of community dwelling older women, modest correlations ranging from -0.46 to -0.64 ($p < .001$) were found between the overall mobility index of Tinetti and postural sway in various stance positions (eyes open: single limb stance; eyes open: double limb stance; eyes closed double limb stance). There was no correlation ($r = 0.06$; $p>.05$) between sway and the Tinetti in the most difficult position of eyes closed in single limb stance (Lichtenstein, Burger, Sheilds, & Shiavi , 1990).

In a study of elderly nursing home residents, correlations ranging from 0.8 to 0.30 were found between postural sway measured on the force platform and functional measures of balance including functional reach, timed walks,

timed chair rise, and a modified Tinetti Index (Thapa, Gideon, Fough, Kormicki, & Ray, 1994). A study of community dwelling frail elderly demonstrated a relationship between all measures postural sway (except eyes closed path length) and sensorimotor deficits, but no relationship between measures of postural sway (path length, area of an ellipse, medial-lateral excursion, and anterior-posterior excursion under conditions of eyes open and closed) and the functional performance measures of standing reach, mobility skills, timed walks, and chair rise (except for a weak correlation of -0.25 between mobility skills and the postural sway measure of path length with eyes open). The authors concluded postural sway does not indicate functional performance (Hughes, Duncan, Rose, Chandler, & Studenski, 1996).

In a study of ambulatory hemiparetic participants, functional balance performance on the BBS and gait velocity was compared to static and dynamic balance measures obtained from the Balance Master (NeuroCom International, Inc., Clackamas OR), a computerized measurement and feedback system. In the static tests, postural sway was measured while the subjects stood as still as possible on the Balance Master platform under the conditions of eyes open, eyes closed and eyes open while attempting to maintain the center of gravity within a target box on a visual display monitor. In the dynamic tests, the subjects shifted their weight from side to side and forward and backward at varying paces and while following a target on the visual display monitor. The test-retest reliability

of the BBS and gait velocity measures were high (ICC = 0.98 and 0.96, respectively). The ICCs for test-retest Balance Master static and dynamic tests ranged from 0.50 to 0.63 and from 0.29 to 0.88, respectively. The functional measures (BBS scores and gait velocity) were strongly correlated ($r = 0.81$; $p < .001$). None of the static Balance Master tests related to either functional measure. The correlations between dynamic Balance Master tests and the BBS ranged from -0.51 to –0.67. The authors concluded that the BBS is a reliable and valid functional balance measure and that the static Balance Master measures of balance did not relate to functional balance performance in hemiplegic subjects (Liston, 1996). In a study of healthy subjects using the Chattecx Balance System (Chattecx Corp, Chattanooga, TN) to determine static and dynamic sway, no association was found between any measure of sway velocity, number of reported falls, or the Tinetti Balance and Gait score (Baloh et al., 1994).

H. Neuropathic diabetic balance

The current literature supports a compromise of balance in neuropathic diabetics as determined by postural sway (Simoneau et al., 1994) and dynamic posturography (Nardo et al., 1999; Uccoli et al., 1995). Neuropathic diabetics are 15 times more likely to report an injurious fall and report decreased perceived levels of safety (Cavanagh et al., 1992). Gait strategies identified in

this population (decreased stride length, slower walking velocity and increased attention to walking) may be compensatory strategies which increase stability during walking. However, it appears the compensatory strategies are not adequate to decrease risk of injurious falls in this population.

It is important to identify high risk diabetics for fall prevention intervention. The Guide to Physical Therapist Practice (1997), a clinical tool describing preferred practice patterns, states that preferred tests and measures for persons with impaired motor function and sensory integrity associated with acute or chronic polyneuropathy include "identification and quantification of static and dynamic balance activities" and "gait, locomotion, and balance profiles." It is important for practice patterns to be supported by specific and thorough research studies.

The influence of diabetic neuropathy on static balance, evidenced by postural sway, has been reported (Simoneau et al., 1994). The clinical value of postural sway as an indicator of dynamic balance performance is unclear (Baloh et al., 1998, Liston et al., 1996). In a recently published review article on postural instability in diabetics with neuropathy, van Deursen and Simoneau (1999) commented on the scarceness of research relative to functional balance performance among diabetics with neuropathy. A valuable contribution to physical therapist practice would be a report of such performance and to determine relationships to falls and fear of falling.

I. Purpose of the study

The purpose of this study is to determine the performance of diabetics and controls on common clinical measures of functional balance and to determine whether diabetic neuropathy is associated with functional balance performance, falls and fear of falling. The study is composed of five parts. The purpose of part one is to determine the relationship between diabetic neuropathy and functional balance performance among groups (among neuropathic diabetics, non-neuropathic diabetics, and controls; among diabetics and controls; and among neuropathic diabetics and non-neuropathic participants). The purpose of part two is to determine the relationship between vibration scores and functional balance performance among diabetics. The purpose of part three is to determine the relationship between diabetic neuropathy, falls and fear of falling among groups. The purpose of part four is to determine the relationship between vibration scores, falls and fear of falling among diabetics. The purpose of part five is to determine the relationship between functional balance performance, falls and fear of falling among diabetics. The research hypothesis relative to part 1 of the study is that there is no relationship between diabetic neuropathy and functional balance performance among groups. The research hypothesis relative to part two of the study is that there is no relationship between vibration scores and functional balance performance among diabetics. The research hypotheses relative to part 3 of the study is that there is no

relationship between diabetic neuropathy, falls and fear of falling among groups. The research hypotheses relative to part four of the study is that there is no relationship between vibration scores, falls and fear of falling among diabetics. The research hypothesis relative to part five of the study is that there is no relationship between functional balance performance, falls and fear of falling among diabetics.

CHAPTER III: METHODS

A. Participants

Forty-two volunteer participants represented three groups (n = 14 per group). Group 1 had diabetes mellitus and significant neuropathy (DM-NP); group 2 had diabetes mellitus and no significant neuropathy (DM); and group 3 had neither diabetes mellitus nor neuropathy (control). Diabetic participants were recruited from Chattanooga area physician offices and clinics specialized in treating diabetes. An established diagnosis of diabetes and indication of ongoing medical supervision was required for diabetic participants. Participants in the non-diabetic, non-neuropathic control group were recruited through advertising. All participants were evaluated in one of the Chattanooga area facilities approved for the study: a rehabilitation hospital, a diabetes clinic and a regional medical center. All participants signed an informed consent statement prior to participation.

B. Criteria for inclusion and exclusion

Vibratory perception threshold (VPT) was assessed on each participant. The VPT was tested with the Bio-thesiometer (Bio-Medical Instrument Co., Newbury, OH), a fixed frequency variable amplitude vibrometer. The vibrometer instrument is a hand held unit consisting of a plastic post, 1.5 cm in

diameter, protruding from a transducer providing a constant vibratory stimulus at an amplitude directly proportional to the square of the applied voltage. The maximal applied voltage is 50 volts. The voltage (and subsequent amplitude of vibration) is adjusted manually. To familiarize participants with the vibration sensation, vibration amplitude was increased to a suprasensory level that the subject could easily detect. The VPT was determined on the great toe by the following protocol: vibration amplitude was increased from zero until the subject reported feeling the vibration sensation. The average of three readings was recorded. The procedure was repeated on the opposite great toe. The participant was determined to have a vibratory perception deficit when the VPT equaled or exceeded the age-adjusted normal VPT values published by Bloom, Till, Sonksen, and Smith (1984). [The upper limit of normal vibration threshold was defined by Bloom et al. as the mean + 2 SD of VPT in healthy subjects for each decade of age].

The Semmes-Weinstein nylon monofilament (SWM), fabricated as a set of 20 monofilaments (Northcoast Medical, San Jose, CA), was used to determine touch-pressure sensation threshold (TPST). Each SWM is assigned a number (ranging from 1.65 – 6.65) representing the log of 10 times the bending force in grams. Higher numbers represent greater bending force; thus the higher the number of SWM determined as the threshold for touch-pressure sensation, the worse the neuropathy. The great toe was tested on each foot. The SWM was

pressed perpendicular to the skin surface with enough pressure to bend the nylon portion. The TPST was determined by the following protocol: the participant responded "yes" each time application of a SWM was sensed at the great toe. Five to 10 trials were given with the SWM. The participant was required to respond correctly to 80% of the trials to receive a given SWM rating. If the subject failed to respond correctly to 80% of the trials, testing proceeded to the next highest level SWM. The TPST was determined as the lowest numbered SWM perceived with 80% accuracy.

Exclusion criteria were employed to control for possible effects other than diabetes and diabetic neuropathy on dynamic stability (adapted from Simoneau et al., 1994). Participants completed a questionnaire and were observed or tested clinically to determine whether criteria were met. Criteria are listed below.

1. Regular use of medications likely to impact stability (cardiac medications were allowed).
2 Orthostatic hypotension, (defined as a drop in SBP after participant moved from sit to stand; blood pressure measured after 5 minutes of sitting and after 2 minutes of standing).
3. Report or clinical evidence of central or peripheral neurological dysfunction (other than peripheral neuropathy attributed to diabetes).

4. Report of consumption of alcohol within 8 hours prior to testing.
5. Evidence of vestibular dysfunction.
6. Clinically apparent or reported evidence of musculoskeletal dysfunction, previous illness or surgery, or any lower extremity abnormality considered by the investigator as likely to impact postural stability.
7. A visual acuity < 20/100, loss of binocular vision, or the presence of double vision led to exclusion.
8. Report of symptoms consistent with exercise induced intermittent claudication.
9. Cognitive dysfunction likely to impact stability.

The vestibular system was evaluated using the "visual acuity during head shaking test" (Sharpe, 1994) in which the participant read a Snellen chart with the head stationary and again while shaking the head from side to side. In persons with no vestibular deficit, visual acuity is the same during head static and head shaking conditions. Subjects exhibiting abnormal findings were excluded from the study. Participants were screened for apparent deformities, arthritic conditions causing pain and difficulty walking or standing, and history of major surgical procedures, major fractures, or other musculoskeletal problems likely to affect mobility and postural stability. Muscle strength of knee

extensors, knee flexors, ankle plantarflexors, ankle dorsiflexors, and toe flexors was determined using standard manual muscle testing techniques (Hislop & Montgomery, 1995). Range of motion (ROM) was determined at the hip, knee, ankle and first metatarsal head using standard goniometric techniques (Norkin & White, 1995). Significant weakness of lower extremity musculature, defined as a manual muscle test grade of less than 3+ or significant limitation in ROM preventing ease in rising from a chair and stepping on a stool led to exclusion. Vision was tested using a Snellen eye chart. Participants were allowed to wear corrective lenses during testing. Diabetic retinopathy was not necessarily a reason for exclusion. The Mini Mental State Exam (MMSE) was used to assess cognitive performance through evaluation of patient performance in an oral component (with a maximal score of 21 points) and a task component (with a maximum score of 9 points). The MMSE has demonstrated good test retest reliability (r=.89), interrater reliability (r=.83), and predictive validity (Folstein, Folstein, & McHugh, 1975). Folstein et al. (1975) reported that a score of < 20 was found only in persons with delirium or dementia. In the current study, participants were excluded when MMSE scores were < 20.

C. Falls and fear of falling

Participants provided a self-report of fall and balance history. A fall was defined as an unintentional change in body posture that resulted in the person being on a lower level. Participants were required to recount the circumstances of each fall included in the analysis. Prior to testing for dynamic balance, participants completed a questionnaire on fear of falling. Participants were asked the question "Are you afraid of falling?" and chose among the responses (1) not at all afraid (2) somewhat afraid (3) very afraid.

Participants completed the Modified Falls Efficacy Scale (MFES), a 14 item questionnaire scored on a 10 point visual analogue scale. The MFES is a measure of self-perceived fear of falling in which higher scores reflect more confidence and less fear of falling. The MFES assesses confidence while performing activities of daily living, such as dressing, bathing, walking, reaching, shopping and gardening. See Appendix 2 for a detailed description of MFES items. The reliability and validity of the MFES has been demonstrated in a study of community dwelling elderly. In a study of community dwelling elderly, the test-retest reliability of the MFES was high (ICC = 0.93) and each item of the test differentiated between non-fallers and persons with balance and mobility dysfunction (Hill, Schwarz, Kalogeropolous, & Gibson, 1996).

D. Dynamic stability testing

The dynamic stability of each eligible participant was tested using the BBS and the TUG tests. The ordering of dynamic stability tests was randomly assigned. All measurements were collected during a single session. A 10 minute rest period was allowed between tests. Participants wore comfortable walking shoes for the tests.

The BBS is a functional assessment of balance performance consisting of 14 items rated on a 5 point ordinal scale (0-4) with a maximum score of 56. See Appendix 3 for a detailed description of test items. The estimated time to complete and score the BBS is 15-20 minutes (Lewis & McNerney, 1997).

The TUG is a record of the time required for the subject to rise from a standard chair, walk 3 meters to a line on the floor, turn, walk back to the chair, and sit down again (Podsiadlo & Richardson, 1991). The estimated time to complete the test is 5 minutes.

CHAPTER IV: RESULTS

A. General

1. Statistics used

The SPSS statistical software package (Version 9.0, Chicago, Illinois) was used for data analysis. Statistical differences were tested at the 0.05 significance level and all tests were two-tailed. Comparisons among groups, between the two diabetic groups and between neuropathic participants (DM-NPs) and non-neuropathic participants (DMs and controls) were conducted. Parametric multiple comparisons were analyzed by the Tukey's b test. Nonparametric multiple comparisons were analyzed by Mann Whitney U test at the significance level of 0.05 divided by the number of comparisons. Additional statistical procedures included Spearman's rank order technique, chi-square and Fisher's exact test. The strength of correlation coefficients was interpreted by guidelines presented in Levin and Fox (1994): ± 0.6 = strong; ± 0.3=moderate; ± 0.1=weak. Partial correlation analysis was calculated with Kendall's tau b as described by Seigel & Castellan (1988).

2. Choice of statistical tests

There is considerable controversy among researchers regarding the employment of parametric and nonparametric analytical procedures, particularly

in analyzing ordinal level data and small sample sizes. The debate apparently stems from disagreements regarding guidelines by Stevens (1946) for the use of parametric tests with at least interval level data and nonparametric statistics for ordinal level data.

Those in opposition to the guidelines point to simulation data in support of their position, stating that parametric tests, such as the ANOVA and t-test, can withstand violations of the assumptions of normality and homogeneity of variance sacrificing little power (Armstrong, 1981), especially if sample sizes are large and equal among groups (Glass, 1972, Gaito, 1959). Some simulation studies indicate valid use of parametric statistics even with samples as small as six, as long as the deviation from normality is not too great (Boneau, 1962). In some cases of extreme non-normality, the investigator may reasonably apply lower significance levels or transform the data to reduce non-normality and heterogeneity of variance (Gaito, 1959). Gaito (1960) suggests that in cases of a small effect of assumption violations, parametric techniques may be used with allowances for the violations in the interpretation of results. Some researchers question the constitution of ordinal and interval level data; differentiating between the two is not always an easy task, as some scales fall somewhere between (Gardner, 1975; Gaito, 1960) and may be treated validly as interval data (Gardner, 1975). Other researchers argue that ordinal data contains information that may be lost in nonparametric analysis (Armstrong, 1981).

Those in support of the guidelines relate arguments to assumptions underlying parametric tests, to include normality and homogeneity of variance (Siegel & Castellan, 1988, Blair 1981). The power of parametric over nonparametric tests is evidenced when parametric assumptions are met, but may demonstrate less power under assumption violations (Harwell, 1988; Blair & Higgins, 1980, Blair, 1981). Simulation studies have demonstrated a modest power advantage of the paired samples t test over the Wilcoxon Signed-Ranks test for samples sizes of 10, 25, and 50 under the condition of a normal distribution. However, under various conditions of non-normal population shapes, the nonparametric test was more often the more powerful test, and often drastically so (Blair & Higgins, 1985). It is concluded by some that, under conditions of non-normality, nonparametric tests are generally more powerful and should be strongly considered especially under conditions of small and unequal sample sizes (Harwell, 1988). Researchers are cautioned regarding generalization of robustness studies beyond the conditions actually reported as capable of withstanding assumption violations (Bradley, 1968).

In addition to considering data distribution and level of measurement, Harwell (1988) and Knapp (1990) recommend using the statistic having more meaning when interpreted. In some cases, it may make more sense to discuss the median or rank-order rather than the mean.

In conclusion, the literature indicates that parametric tests generally exert a power advantage (i.e. are able to correctly reject a null hypothesis) when the assumptions underlying the test are met. Though some parametric procedures appear capable of withstanding assumption violations, there is no agreement among researchers on the conditions constituting invalid use of some parametric tests (Siegel & Castellan, 1988; Armstrong, 1981; Knapp, 1990). The most critical issue is the ability of data to meet the requirements of the test; the level of measurement should not be the sole factor (Pett, 1997; Knapp, 1990; Armstrong, 1981, Harwell, 1988). However, there is little agreement regarding the minimal test requirements.

In this study, careful statistical and non-statistical observations were conducted on the ability of the data to meet test assumptions. Statistical measures included skewness coefficient calculation and tests of normality and homogeneity of variance. Non-statistical considerations included examination of sample size and equality among groups, level of measurement and visual observation of the normality distribution. Parametric tests were considered the statistical procedure of choice when the underlying assumptions of normality and homogeneity of variance were reasonably met. Nonparametric tests were preferred for all other analyses.

The distributions of the dependent variables were examined for all participants and by subgroups. As some researchers consider visual inspection a

necessary and critical activity in normality analysis (Blair, 1981; Harwell, 1988; Pett 1997), particular attention was given to visual analysis. Visual observation included comparison of the shape of each distribution to the normal distribution and inspection of boxplots, normal probability plots and detrended probability plots. The Fisher skewness coefficient and statistical tests of normality (Kolmogorov-Smirnov Lilliefors test and Shapiro-Wilks test) were calculated for each dependent variable. The null hypothesis of normal distribution of scores on the dependent variable was rejected when a preliminary determination of skewness on visual inspection was confirmed statistically by both of the following conditions: (1) significance on Fisher skewness coefficient, with significance defined as ± 1.96 (Pett, 1997) (2) significance on the both statistical tests of normality at the .05 significance level. The effect of transformations on the data was investigated for skewed distributions using the same criteria. An additional requirement for strength and ROM was that data on the majority of muscle groups and joint motions meet criteria in order for the null to be rejected regarding these variables.

Homogeneity of variance was evaluated by comparing variances among groups and by the Levene test of homogeneity of variance. The null hypothesis of equal variances among groups was rejected if both of the following conditions were met: (1) the variance of one group was more than twice that of another (2) the Levene test was significant. An additional requirement for

strength and ROM was that data on the majority of muscle groups and joint motions meet criteria in order for the null to be rejected on these variables.

The variables for age, duration of diabetes, BMI, VPT, age-standardized VPT scores (AS-VPT), BBS, TUG, falls, MMSE, fear of falling, strength and ROM were evaluated according to the criteria adopted by the author. The null hypothesis of normality was not rejected for the dependent variables of age, duration of diabetes, AS-VPT, ROM and BMI. The null hypothesis of homogeneity of variance was not rejected on the dependent variables of age, duration of diabetes, AS-VPT, ROM, BMI, BBS and TUG.

The null hypotheses for normality and homogeneity of variance were accepted on the variables of age, duration of diabetes, AS-VPT, and BMI. The off scale measures obtained for 3 subjects on VPT scores (>50 volts) and for 2 subjects for SWM score (>6.65) rendered the median score for the variables of VPT, AS-VPT and SWM the preferred measure of central tendency. Given the small sample size and inability of the majority of dependent variable distributions to meet parametric test assumptions, the author considered nonparametric statistical procedures most appropriate for this study. However, for the purpose of comparison to previously published studies, some parametric statistical procedures were performed. Although the primary interest of this study concerns diabetics, relationships among all participants and within groups are reported.

3. General Participant Characteristics

Sixty-one persons were initially screened for inclusion in the study. Fifty-four of the screened persons were tested. Twelve of the tested participants were excluded from the study for the following reasons: responded inconsistently to questions (N=3), exhibited profound visual deficit (N=1), reported recent eye surgery (N=1), reported previous back surgery (N=1), reported previous lower extremity musculoskeletal surgery or condition considered by author to be function-limiting (N=5), reported recent undiagnosed knee injury (N=1). Of the remaining forty-two study participants, 28 were diabetic and 14 were non-diabetic and non-neuropathic. Diabetic participants with AS-VPT scores > 1.96 were placed in the DM-NP group (N=14). All diabetics with AS-VPT scores < 1.96 were placed into the DM group (N=14). The participants with no known diabetes were placed in the control group (N=14). All members of the control group demonstrated AS-VPT scores < 1.96.

The means and standard deviations for groups on age were as follows: DM-NP = 49.6 ($\pm$11.7); DM = 53.6 ($\pm$10.5); control = 51.1($\pm$9.5). The means and standard deviations of groups on BMI were as follows: DM-NP =29.3 ($\pm$6.7); DM = 33.2 ($\pm$6.4); control = 28.5($\pm$5.8). A one way ANOVA and Kruskal Wallis one way ANOVA demonstrated no significant differences among groups on the physical characteristics of age (F=.525, p=.596; x^2=1.099, p=.577) and BMI (F=2.253, p=.119; x^2=4.512, p=.105).

The male to female ratio in each group was as follows: DM-NP = 4:10; DM = 4:10; control = 3:11. The ratio of Type 1 to Type 2 diabetes in the DM-NP and DM groups were 3:11 and 2:12, respectively. The means and standard deviations for duration of diabetes were 15.9 (±10.0) in the DM-NP and 8.6 (±6.5) in the DM group. The median score for duration of diabetes in the DM-NP and DM groups were 17 and 8 years, respectively. The results of an independent samples t test and Mann Whitney U demonstrated a significant difference between the two diabetic groups on duration of diabetes (t=-2.309, p=.029; z=-2.049, p=.041).

The median score on the MMSE for all participants was 28. The median score within the DM-NP, DM and control group was 28, 28 and 29, respectively. The average absolute deviation from median scores for the DM-NP, DM, and control groups were 0.86, 1.5, and 0.71, respectively. The Kruskal Wallis one way ANOVA demonstrated a significant difference (x^2=9.516, p=.009) among groups on MMSE scores. The Mann-Whitney U test demonstrated a significant difference (p=.003) between the DM and control groups on MMSE scores and no significant differences (p > .0167) for other group comparisons. See Appendix 4 for a summary table of participant characteristics.

4. Specific participant characteristics

ROM

With all cases analyzed, a dependent samples t test and Wilcoxon Signed Ranks test demonstrated significant differences in ROM between the right and left sides on hip flexion (t= -2.147, p=.038; z= -2.092, p=.036), knee flexion (t= -2.827, p = .007; z= -2.435, p=.015) and ankle dorsiflexion (t= -2.213, p=.033; z= -2.066, p= .039), but not first metatarsal extension (t=.703, p=.486). Among diabetics, there was a significant difference between the right and left sides for knee flexion (t=-3.598, p=.001; z=-3.053, p=.002), but no significant difference between the right and left sides for hip flexion (t-1.92, p=.065; z=-1.815, p=.07), ankle dorsiflexion (t=-1.77, p=.087; z=-1.815, p=.07) and metatarsal extension (t=.812, p=.424; z=-.808, p=.419). With each group analyzed individually, only the DM group demonstrated a significant difference in ROM between right and left sides; the significant difference was in knee flexion (t=-3.434, p=.004; z=-2.27, p=.007).

The one way ANOVA and Tukey's b test demonstrated greater left hip flexion in controls than DM-NPs, whereas the Kruskal Wallis one way ANOVA demonstrated no significant difference among groups for left hip flexion. The result of Tukey's b indicated greater right and left knee flexion in controls than DM-NPs and DMs and greater left metatarsal extension in controls than DMs. There were no significant differences in other group comparisons. The Mann

Whitney U indicated greater right knee flexion in controls than DM-NPs and DMs, and greater left knee flexion and left metatarsal extension in controls than DMs. See Appendix 5 for specific statistical test values and Appendix 6 for a summary table of ROM measurements for each group and significant differences among groups.

Strength

When analyzed among all participants, the result of the Wilcoxon Matched Pairs Signed-Ranks test indicated no significant differences in strength grades as determined by manual muscle testing between right and left sides (knee extension = -.577, p=.564; plantarflexion z= -.577, p=.564; dorsiflexion z = -1.0, p=.317; toe flexion z= -1.0, p=.317; toe extension z= -.00, p=1.0). Among diabetics, the result of the Wilcoxon Matched Pairs Signed-Ranks test indicated no significant differences in strength grades between right and left sides (knee extension = -.577, p=.564; plantarflexion z= -.00, p=1.0; dorsiflexion z = -1.0, p=.317; toe flexion z= -1.0, p=.317; toe extension z= -.00, p=1.0).

The result of the Kruskal Wallis one way ANOVA and Mann Whitney U multiple comparison procedure indicated greater strength among controls than DM-NPs on right and left ankle plantarflexion, toe flexion and toe extension. There were no significant differences between the DM-NPs and DMs and between DMs and controls on strength grades. See Appendix 5 for specific

statistical test values and Appendix 7 for a summary table of strength data among groups.

Vibration scores and SWM scores

The results of the dependent samples t test and Wilcoxon Signed Ranks test demonstrated no significant difference between the VPT scores of the right and left feet when analyzed among all participants (t=-1.649, p=.107; z=-1.711, p=.087) and among diabetics (t=-1.404, p=.172; z=-1.618, p=.106). Therefore, the VPT values for the right and left foot were averaged for each subject, representing a single VPT score. Each VPT score (volts) was $\log_{10}$ transformed and expressed as the standard deviation from the age-related mean relative to normal values published by Bloom et al. (1985), thus yielding the AS-VPT score.

The results of the dependent samples t test and Wilcoxon Signed Ranks test demonstrated no significant difference in SWM scores between the right and left feet when analyzed among all participants (t=-.459, p=.649; z=-.330, p=.742) and when analyzed among diabetics (t=-.599, p=.554; z=-.501, p=.616). Therefore, the SWM values for the right and left foot were averaged for each participant, representing a single SWM score. There was a significant correlation between the SWM and VPT measures (rho=.71, p=.00), between the SWM and AS-VPT measures (rho=.70, p=.00) and between VPT and AS-VPT measures (rho=.93, p=.00).

The mean (standard deviation) for VPT was 40.43 (±10.62) in the DM-NP group, 17.0 (±6.82) in the DM group, and 11.93 (±4.8) in the control group. The median (average absolute deviation from the median) for VPT in each group was as follows: DM-NP = 44.5 (8.07); DM = 16.25 (5.64); control = 10.75 (3.36). The mean (standard deviation) for AS-VPT was 2.82 (±.57) in the DM-NP group, 0.48 (±.72) in the DM group, and -0.29 (±.82) in the control group. The median (average absolute deviation from the median) for AS-VPT in each group was as follows: DM-NP = 2.8 (.48); DM = .445 (.50); control = -0.29 (.59).

The results of a one way ANOVA and Kruskal Wallis one-way ANOVA demonstrated significant differences on VPT, AS-VPT and SWM among groups. The results of the Tukey's B and Mann Whitney U indicated significantly greater VPT scores in the DM-NPs than the DMs and controls and no significant difference in VPT scores between the DMs and controls. The results of the Tukey's B and Mann Whitney U indicated significant differences among all groups on AS-VPT (DM-NPs > DMs > controls). A post-hoc analysis utilizing the average difference in mean rank (ADMR) procedure described by Siegel and Catellan (1988) demonstrated a significant difference in AS-VPT scores between the DM-NP and control group and between the DM-NP and DM group, but no difference between the DM and control groups. The calculated ADMR for a 3 group comparison of the group size utilized in this study must

exceed 11.1 for significance. The calculated ADMR between the DM-NP and DM group, between the DM-NP and control group and between the DM and control group was 17.04, 24.96 and 7.92, respectively. The results of the Tukey's B and Mann Whitney U indicated significantly greater SWM scores among DM-NPs than DMs and control and no significant difference between DMs and controls. See Appendix 5 for specific statistical test values.

There was a no relationship between age and VPT among all participants (rho=.26, p=.097) and among diabetic participants (rho = .20, p=.299). There was a significant positive relationship between age and VPT scores within the DM-NP (rho=.54, p=.047) and DM group (rho=.70, p=.006), but not within the control group (rho=.50, p=.067). There was no relationship between AS-VPT and age among all participants (rho=-.07, p=.649), among diabetic participants (rho=-.17, p=.380) and within groups [(DM-NP rho=-.29, p=.314); (DM rho=.35, p=.215); (control rho=-.06, p=.852)].

There was no significant relationship between duration of diabetes and VPT scores among diabetics (rho=.34, p=.076), within the DM-NP group (rho=.36, p=.201) and within the DM group (rho=-.12, p=.677). There was no significant relationship between duration of diabetes and VPT scores with age held constant when analyzed among diabetics (T=.224; p>.05), within the DM-NP group (T=.354, p>.05) and within the DM group (T=-.183, p>.05).

There was a significant relationship between duration of diabetes and AS-VPT among diabetics (rho=.42, p=.027), but no significant relationship within the DM-NP group (rho=.50, p=.070) and DM group (rho=-.20, p=.499). There was a significant relationship between duration of diabetes and AS-VPT with age held constant when analyzed among diabetics (T=.28, p<.05), but not within the DM-NP group (T=.34, p>.05) and within the DM group (T=-.20, p>.05).

There was a significant negative relationship between VPT and strength of the plantarflexors when analyzed among all participants [right plantarflexors (rho=-.56, p=.00); left plantarflexors (rho=-.55, p=.00)] and among diabetics [right plantarflexors (rho=-.44, p=.018); left plantarflexors (rho=-.39, p=.04)]. There was a significant relationship between AS-VPT and strength of the plantarflexors when analyzed among all participants [right plantarflexors (rho=-.46, p=.002); left plantarflexors (rho=-.47, p=.002)]. Among diabetics, there was a significant negative relationship between AS-VPT and strength of the right plantarflexors (rho=-.39, p=.041), but not the left plantarflexors (rho=-.33, p=.085).

Among all participants, there was a significant relationship between VPT and strength of the right dorsiflexors (rho=-.33, p=.038), but not the left dorsiflexors (rho=-.22, p=.161). Among diabetics, there was no significant relationship between VPT and strength of the dorsiflexors [right dorsiflexors

(rho=-.27, p=.165); left dorsiflexors (rho=-.13, p=.517)]. There was no significant relationship between AS-VPT and strength of the dorsiflexors when analyzed among all participants [right dorsiflexors (rho=-30, p=.051); left dorsiflexors (rho=-.20, p=.204)] and among diabetics [right dorsiflexors (rho=-.27, p=.166); left dorsiflexors (rho=-.12, p=.552)]. See Appendix 4 for a summary table on vibration and SWM scores. See Appendix 5 for specific statistical test values.

Clinical dynamic balance measures

The relationship between TUG and BBS score was examined among all participants and among diabetics. There was a significant negative relationship between the TUG score and BBS score among all participants (rho=-.71, p=.00) and among diabetics (rho=-.78, p=.00).

B. Results relative to part one of the study: Relationship between diabetic neuropathy and functional balance performance among groups

1. Performance on TUG

TUG score descriptives

The mean (standard deviation) of TUG scores within groups was as follows: DM-NP = 8.03 (±2.09); DM = 6.89 (±1.6); control = 6.21 (±1.22). The

median (average absolute deviation from the median) for performance on the TUG within groups was as follows: DM-NP = 7.69 (1.55); DM = 6.28 (1.25); control = 5.6 (.91).

TUG scores and neuropathy

The result of a one way ANOVA and Kruskal Wallis one way ANOVA indicated a significant difference among groups on performance on the TUG ($F=4.228$, $p=.022$; $x^2=6.515$, $p=.038$). The Tukey's B and Mann Whitney U indicated the DM-NP group was significantly slower than the control group, but there was no significant difference in performance on TUG between the DM-NP and DM group and between the DM and control group. The results of the independent t test and Mann Whitney U indicated diabetics were significantly slower than controls and neuropathic participants were significantly slower than non-neuropathic participants. See Appendix 5 for specific statistical test values. See Appendix 8 for a summary table of performance on balance tests and Appendix 9 for a graphical representation of balance test results.

2. Performance on BBS

BBS scores among groups

The median score (range) on total BBS was 51 (46-56) for the DM-NP group and 56 (46-56) for the DM group. All participants in the control group scored a 56, the highest possible, on the BBS. The absolute deviation from the

median score for the DM-NP, DM and control groups were 3.14, 1.86 and 0, respectively. The number of tied scores on the BBS in the DM-NP group was as follows: BBS = 50 (N=3), BBS = 56 (N=2). The number of tied scores in the DM group was as follows: BBS = 52 (N=3), BBS = 56 (N=8).

BBS scores and neuropathy

The Kruskal Wallis one way ANOVA of ranks revealed a statistically significant difference among groups on total BBS score (x^2 = 19.09; p=.00). Results of the Mann Whitney U indicated significantly lower scores among DM-NPs than controls and among DMs than controls, but no significant difference in scores between DM-NPs and DMs. Results of the Mann Whitney U indicated significantly lower scores among diabetics than controls and among neuropathic participants than non-neuropathic participants. See Appendix 5 for specific statistical test values.

BBS items

Participants in all groups scored a 4, the highest score possible, on items 1-5, 7, 10 and 11; thus items 1-5, 7, 10 and 11 were excluded from the analysis. The control group scored a 4 on all 14 items of the BBS instrument. See Appendix 10 for specific BBS item data.

Analysis of the correlation between BBS items 6, 8, 9, 12, 13, and 14 and total BBS score indicated that BBS item 8 (rho=.69), item 12 (rho=.58), item 13 (rho=.82) and item 14 (rho=.93) were significantly correlated (p=.00)

with total BBS score among diabetics, whereas item 6 (rho=.19, p=.297) and item 9 (rho=.07, p=.695) were not significantly correlated.

BBS items and neuropathy

The Kruskal Wallis one way ANOVA on BBS items 6, 8, 9 and 12-14 indicated significant differences among groups in scoring BBS item 8 (x^2=6.359, p=.042), item 13 (x^2=8.819, p=.012) and item 14 (x^2=18.491, p=.00). On item 8, the results of Mann Whitney U indicated significantly lower scores among DM-NPs than controls, but no significant difference in scores between the DM-NP and DM group and between the DM and control group. On item 13, the results of Mann Whitney U indicated significantly lower scores among DM-NPs than controls and among DMs than controls, but no difference in scores between DM-NPs and DMs. On item 14, results of the Mann Whitney U indicated significantly lower scores among DM-NPs than DMs and controls and significantly lower scores among DMs than controls. The diabetics scored significantly lower than controls on BBS items 8, 12, 13 and 14. The neuropathic participants scored significantly lower than non-neuropathic participants on BBS items 8, 13 and 14, but not item 12. See Appendix 5 for specific statistical test values. See Appendix 8 for a summary table of BBS data and Appendix 9 for a graphical representation of balance test results.

C. Results relative to part two of the study: Relationship between vibration scores and functional balance performance among diabetics

1. Performance on TUG

TUG and vibration scores

There was no relationship between TUG scores and VPT scores among diabetics (rho=.34, p=.073) and within groups [DM-NP (rho=-.16, p=.582); DM (rho=.33, p=.257)]. There was no relationship between TUG scores and AS-VPT scores among diabetics (rho=.26, p=.178) and within groups [DM-NP (rho=-.27, p=.436); DM (rho=.28, p=.333)].

TUG and duration of diabetes

There was a significant negative relationship between TUG and duration of diabetes when analyzed within the DM-NP group (rho=-.60, p=.022). There was no significant relationship between TUG and duration of diabetes when analyzed within the DM group (rho=-.19, p=.521) and among diabetics (rho=-.26, p=.180).

TUG and strength

There was a significant negative relationship between TUG scores and strength of the plantarflexors among diabetics [right plantarflexors (rho=-.60, p=.001); left plantarflexors (rho=-.68, p=.00] and within the DM group [right

plantarflexors (rho=-.83, p=.00); left plantarflexors (rho=-.84, p=.00), but not within the DM-NP group [right plantarflexors (rho=-.30, p=.30); left plantarflexors (rho=-.45, p=.111).

There was a significant negative relationship between TUG scores and strength of the dorsiflexors among diabetics [right dorsiflexors (rho=-.50, p=.007); left dorsiflexors (rho=-.47, p=.013)], but not within the DM-NP group [right and left dorsiflexors (rho=-.39, p=.165) and the DM group [right dorsiflexors (rho=-.46, p=.101); left dorsiflexors (rho=-.45, p=.103)]. See Appendix 11 for a summary table of correlations among diabetics.

TUG, age and vibration scores

There was no significant relationship between TUG and age among diabetics (rho=.36, p=.06) and within groups [(DM-NP rho=.26, p=.374); DM (rho=.48, p=.086)]. There was no significant relationship between TUG and age with VPT held constant when analyzed among diabetics (T=.22, p>.05) and within groups [DM-NP (T=.33); DM (T=.29)]. There was a significant relationship between TUG and age with AS-VPT held constant among diabetics (T=.30, p<.05), but not within groups [DM-NP (T=.35, p>.05); DM (T=.34, p>.05].

There was no relationship between TUG scores and VPT with age held constant when analyzed among diabetics (T=.15, p>.05) and within groups (DM-NP (T=-.38); DM (T=.05)]. There was no relationship between TUG and

AS-VPT with age held constant when analyzed among diabetics (T=.19, p>.05) and within groups [(DM-NP (T=-.13); DM (T=.19)]. See Appendix 12 for a summary table of partial correlations among diabetics.

2. Performance on BBS

BBS and vibration scores

There was a significant negative relationship between BBS and VPT scores among diabetics (rho=-.64, p=.00) and within the DM group (rho=-.72, p=.004), but not within the DM-NP group (rho=-.16, p=.575). There was a statistically significant negative relationship between BBS scores and age in the DM group (rho=-.64; p=.015), but not among diabetics (rho=-.29, p=.131) and within the DM-NP group (rho=-.05, p=.856). There was a significant negative relationship between the BBS score and VPT score with age held constant among diabetics (T=-.45, p<.05) and within the DM group (T=-.45, p<.05), but not within the DM-NP group (T=-.13, p>.05).

There was a significant negative relationship between BBS and AS-VPT scores among diabetics (rho=-.57, p=.002) and within the DM group (rho=-.57, p=.032), but not within the DM-NP group (rho=-.24, p=.409). There was a significant negative relationship between the BBS score and AS-VPT score with age held constant among diabetics (T=-.44, p<.05) and within the DM group (T=-.43, p<.05), but not within the DM-NP group (T=-.19, p>.05).

BBS and strength

There was a significant positive relationship between BBS scores and strength of the plantarflexors among diabetics [right plantarflexors (rho=.61, p=.001); left plantarflexors (rho=.64, p=.00)]. Within the DM group, there was a significant positive relationship between BBS score and strength of the plantarflexors [right plantarflexors (rho=.90, p=.00); left plantarflexors (rho=.86, p=.00)], but not within the DM-NP group [right plantarflexors (rho=.19, p=.517); left plantarflexors (rho=.34, p=.229)].

There was a significant positive relationship between BBS scores and strength of the dorsiflexors among diabetics [right dorsiflexors (rho=.51, p=.005); left dorsiflexors (rho=.39, p=.039)] and within the DM group for right dorsiflexors (rho=.62). There was no significant relationship between BBS scores and strength of the right and left dorsiflexors within the DM-NP group (rho=.36, p=.211) and between BBS scores and left dorsiflexors within the DM group (rho=.39, p=.174). See Appendix 11 for a summary table of correlations among diabetics.

BBS, vibration scores and strength of plantarflexors

There was a significant negative relationship between BBS and VPT with strength of the right plantarflexors held constant among diabetics (T=-.35, p<.05), but not within each group [DM-NP (T=-.18, p>.05); DM (T=-.41, p>.05)]. There was a significant negative relationship between BBS and VPT

with strength of the left plantarflexors held constant among diabetics (T=-.29, p<.05), but not within each group [DM-NP (T=-.18, p>.05; DM T=-.27, p>.05)]. There was a significant negative relationship between BBS and AS-VPT with strength of the right plantarflexors held constant among diabetics (T=-.32, p<.05), but not within each group [DM-NP (T=-.22, p>.05); DM (T=-.21, p>.05)]. There was a significant negative relationship between BBS and AS-VPT with strength of the left plantarflexors held constant among diabetics (T=-.340, p<.05), but not within each group [DM-NP (T=-.23, p>.05); DM (T=-.31, p>.05). See Appendix 12 for a summary table of partial correlations among diabetics.

BBS, vibration scores and strength of dorsiflexors

There was a significant negative relationship between BBS and VPT with strength of the right dorsiflexors held constant among diabetics (T=-.42, p<.05) and within the DM group (T=-.49, p<.05), but not within the DM-NP group (T=-.19, p>.05;). There was a significant negative relationship between BBS and VPT with strength of the left dorsiflexors held constant among diabetics (T=-.46, p<.05) and within the DM group (T=-.58, p<.05), but not within the DM-NP group (T=-.19, p>.05). There was a significant negative relationship between BBS and AS-VPT with strength of the right dorsiflexors held constant among diabetics (T=-.49, p<.05), but not within each group [DM-NP (T=-.16, p>.05); DM (T=-.32, p>.05)]. There was a significant negative

relationship between BBS and AS-VPT with strength of the left dorsiflexors held constant among diabetics (T=-.40, p<.05) and within the DM group (T=-.48, p>.05), but not within the DM-NP group (T=-.16, p>.05). See Appendix 12 for a summary of partial correlation data among diabetics.

BBS items and vibration scores

There was a significant negative relationship between BBS item 8 scores and VPT among diabetics (rho=-.33, p=.084) and within the DM group (rho=-.56, p=.038), but not within the DM-NP group (rho=.07, p=.801). There was no significant relationship between BBS item 12 scores and VPT among diabetics (rho=-.22, p=.27) and within groups [DM-NP (rho=-.01, p=.962); DM (rho=-.36, p=.206)]. There was a significant negative relationship between BBS item 13 scores and within the DM group (rho=-.77, p=.001), but not among diabetics (rho=-.35, p=.066) and within the DM-NP group (rho=-.24, p=.402). There was a significant relationship between BBS item 14 scores and VPT among diabetics (rho=-.65, p=.00) and within the DM group (rho=-.83, p=.00), but not within the DM-NP group (rho=-.24, p=.416).

There was no significant relationship between item 8 scores and AS-VPT scores among diabetics (rho=-.35, p=.066) and within groups [DM-NP (rho=-.12, p=.659); DM (rho=-.51, p=.065)]. There was no significant relationship between BBS item 12 scores and AS-VPT scores among diabetics (rho=-.21, p=.293), within the DM-NP group (rho=-.08, p=.779) and within the DM group

(rho=-.44, p=.117). There was a significant relationship between item 13 scores and AS-VPT within the DM group (rho=-.55, p=.041), but not among diabetics (rho=-.35, p=.066) and within the DM-NP group (rho=-.33, p=.245). There was a significant relationship between item 14 scores and AS-VPT scores among diabetics (rho=0.65, p=.00) and within the DM group (rho=0.64, p=.014), but not within the DM-NP group (rho=-.33, p=.255). See Appendix 13 for a summary of correlations with BBS items among diabetics.

BBS items and strength of the plantarflexors

There was a significant relationship between strength of the right plantarflexors and BBS item 8 scores within the DM group (rho=.57, p=.034), but not among diabetics (rho=.36, p=.058) and within the DM-NP group (rho=.12, p=.689). There was a significant relationship between strength of the right plantarflexors and BBS item 12 scores within the DM group (rho=.79, p=.005), but not among diabetics (rho=.33, p=.091) and within the DM-NP group (rho=-.13, p=.658). There was a significant relationship between strength of the right plantarflexors and BBS item 13 scores among diabetics (rho=.43, p=.024) and within the DM group (rho=.70, p=.005), but not within the DM-NP group (rho=.13, p=.651). There was a significant relationship between strength of the right plantarflexors and BBS item 14 scores among diabetics (rho=.51, p=.005) and within the DM group (rho=.78, p=.001), but not within the DM-NP group (rho=.12, p=.693).

There was a significant relationship between strength of the left plantarflexors and BBS item 8 scores within the DM group (rho=.57, p=.034), but not among diabetics (rho=.36, p=.058) and within the DM-NP group (rho=.20, p=.499). There was a significant relationship between strength of the left plantarflexors and BBS item 12 scores among diabetics (rho=.40, p=.036) and within the DM group (rho=.83, p=.00), but not within the DM-NP group (rho=-.07, p=.803). There was a significant relationship between strength of the left plantarflexors and BBS item 13 scores among diabetics (rho=.43, p=.024) and within the DM group (rho=.62, p=.018), but not within the DM-NP group (rho=.23, p=.436). There was a significant relationship between strength of the left plantarflexors and BBS item 14 scores among diabetics (rho=.51, p=.005) and within the DM group (rho=.69, p=.006), but not within the DM-NP group (rho=.27, p=.355). See Appendix 13 for a summary table of correlations with BBS items among diabetics.

BBS items and strength of the dorsiflexors

There was a significant relationship between strength of the right dorsiflexors and BBS item 8 scores among diabetics (rho=.70, p=.00) and within the DM group (rho=1.0, p=.00), but not within the DM-NP group (rho=.52, p=.057). There was no significant relationship between strength of the right dorsiflexors and BBS item 12 scores among diabetics (rho=.32, p=.097), within the DM-NP group (rho=.27, p=.349) and within the DM group (rho=.35,

p=.216). There was a significant relationship between strength of the right dorsiflexors and BBS item 13 scores within the DM group (rho=.56, p=.037), but not among diabetics (rho=.25, p=.196) and within the DM-NP group (rho=-.02, p=.943). There was a significant relationship between strength of the right dorsiflexors and BBS item 14 scores among diabetics (rho=.52, p=.004) and within the DM group (rho=.59, p=.025), but not within the DM-NP group (rho=.45, p=.109).

There was a significant relationship between strength of the left dorsiflexors and BBS item 8 scores among diabetics (rho=.62, p=.00) and within the DM group (rho=.78, p=.001), but not within the DM group (rho=.52, p=.057). There was no significant relationship between strength of the left dorsiflexors and BBS item 12 scores among diabetics (rho=.26, p=.189), within the DM-NP group (rho=.27, p=.349) and within the DM group (rho=.21, p=.47). There was no significant relationship between strength of the left dorsiflexors and BBS item 13 scores among diabetics (rho=.17, p=.386), within the DM-NP group (rho=-.02, p=.943) and within DM group (rho=.35, p=.216). There was a significant relationship between strength of the left dorsiflexors and BBS item 14 scores among diabetics (rho=.41, p=.031) but not within the DM-NP group (rho=.45, p=.109) and within the DM group (rho=.38, p=.181). See Appendix 13 for a summary table of correlations between strength and BBS items among diabetics.

BBS items, vibration and strength of ankle muscles

With strength of the plantarflexors held constant, there was a significant relationship ($p<.05$) between VPT and BBS item 13 scores [right (T=-.35); left (T=-.37)] and item 14 [right (T=-.56); left (T= -.57)], but not item 8 scores [right (T=-.249); left (T=-.261)] and item 12 [right (T=-.136); left (T=-.123). With strength of the dorsiflexors held constant, there was a significant relationship ($p<.05$) between VPT and BBS item 8 scores [right (T=-.36); left (T=-.45)], item 13 [right (T=-.43); left (T=-.45)] and item 14 scores [right (T=-.64); left (T=-.66)], but not item 12 scores [right (T=-.16); left (T=-.21)]. See Appendix 12 for summary of partial correlation data among diabetics.

D. Results relative to part three of the study: Relationship between diabetic neuropathy, falls and fear of falling among groups

1. Relationship between diabetic neuropathy and history of falls

Descriptive data on falls

Evaluation of reported fall history revealed an unusually high number of falls (n=7 and n=12) for two participants in the DM-NP group. Data analysis revealed the Z scores on falls of the participants with 7 and 12 reported falls to be 2.7 and 5, respectively. The participants reporting 7 and 12 falls were

female and male, respectively. All fall and fear data were analyzed with data from participants reporting 7 and 12 falls excluded. Some analyses were conducted with falls data collapsed into two groups: high fallers (those who fell $\geq$ two times in the past year) and low-fallers (those who reported $\leq$ 1 fall in the past year). The high and low falls criteria were chosen as multiple falls may be more predictable in identifying falls related to chronic disorders than single falls (Nevitt et al., 1989).

The total number of falls reported among all participants and among diabetics was 29 and 23, respectively. The median score for falls was 0 in all groups and the range of falls was 0-5 in the DM-NP group, 0-4 in the DM group and 0-2 in the control group. The average number of falls was 0.73 ($\pm$ 1.32) among the 40 participants, 0.88 ($\pm$1.5) among diabetics, 1.0 ($\pm$1.65) in the DM-NP group, 0.79 ($\pm$1.48) in the DM group and 0.43 ($\pm$.76) in the control group. The percentage of participants reporting $\geq$2 falls in the past year was 33% (4/12) in the DM-NP group, 21% (3/14) in the DM group and 14% (2/14) in the control group. There was no significant relationship between duration of diabetes and number of reported falls (rho=.17, p=.413).

Falls and neuropathy

Results of both the one way ANOVA and Kruskal Wallis one way ANOVA indicated no significant difference among groups on number of reported falls (F=.616, p=.546; x^2=.367, p=.832). There was no significant

difference in fall history between diabetics and controls (z=-.491, p=.624) and between neuropathic and non-neuropathic participants (z=-.547, p=.584). See Appendix 14 for a summary table of fall data among groups.

The chi square analysis on the association between group membership and fall category was not conducted as > 20% of the cells had expected frequencies < 5 when analyzed with 3 group categories, when analyzed with diabetic groups collapsed, and when analyzed with non-diabetic groups collapsed. Therefore, groups were collapsed for calculation of the Fisher exact test. Results of the Fisher exact test indicated no significant association between fall category and group membership (diabetics and controls; p=.453), group membership (neuropathic and non-neuropathic; p=.411) and group membership (DM-NP and DM, p=.665). There was no significant difference between fall categories on VPT (z=-1.448, p=.148) and AS-VPT (z=-1.532, p=.126) among diabetics.

2. Relationship between diabetic neuropathy and reported fear of falling

Fear descriptives

Among all participants, 25 reported "not at all afraid of falling," 15 reported "somewhat afraid of falling" and 2 reported "very afraid of falling." The number of participants reporting "not at all afraid of falling" in the DM-NP,

DM and control groups were 5, 8 and 12, respectively. The number of participants reporting "somewhat afraid of falling" in the DM-NP, DM and control groups were 7, 6 and 2, respectively. The two participants reporting "very afraid of falling" were in the DM-NP group. One of the fall outliers reported "very afraid of falling" and the other reported "somewhat afraid." Due to the reported relationship between falls and fear of falling (Tinetti, 1988; Vellas, 1997), all fear data were analyzed with data from the two falls outliers excluded. For the purpose of data analysis, all participants reporting "somewhat afraid of falling" and "very afraid of falling" were collapsed into one group; thus, all fear data were analyzed with two fear groups: "not fearful" and "fearful." Among diabetics, the ratio of males to females in the "not fearful" and "fearful" groups were 6:7 and 1:12, respectively. In the diabetic group, the percentage of males reporting "not fearful" and "fearful" was 86% and 14%, respectively. The percentage of females reporting "not fearful" and "fearful" was 37% and 63%, respectively. See Appendix 14 for summary table of fear data among groups.

Fear and neuropathy

The results of chi-square analysis indicate no association between group membership and reported fear ($x^2 = 5.613$, p=.06). With the non-neuropathic groups collapsed into one, the chi-square analysis was not conducted as > 20% of cells had expected frequencies < 5. The Fisher exact test demonstrated no

association (p=.091) between the fear group ("not fearful" and "fearful") and the collapsed groups of neuropathic participants and non-neuropathic participants. The chi-square analysis demonstrated a significant association between fear group and the collapsed groups of diabetics and controls (x^2 = 4.952, p=.026). The Fisher exact test demonstrated no association between gender and fear group when analyzed among all participants (p=.06) and among diabetics (p=.073).

Performance on MFES and neuropathy

In a Kruskal Wallis analysis, there was a significant difference among groups on scoring of MFES item 2 (x^2=7.149, p=.028), item 7 (x^2=6.79, p=.034) and item 10 (x^2=6.473, p=.039). On scoring of items 2, 7 and 10, the results of Mann Whitney U indicated significantly lower scores among DM-NPs than controls, but no significant difference between DM-NPs and DMs and between DMs and controls. Descriptive data on MFES scores and significant differences among groups is included in Appendix 15. See Appendix 5 for specific statistical test values.

Gender differences on MFES items

Among diabetics, within the DM-NP group and within the DM group, the average MFES score reported by males was greater than the average MFES score reported by females on all items. Within the control group, the average score reported by males greater than or equal to the average score reported by

females for all items except items 1, 8 and 12. Within the control group, the average score for males on MFES items was 10 (±0) on all items except item 1, 8, and 12, whereas the average score for females within the control group was 10 (±0) on all items except items 3, 8, and 11-14. Within the DM and control groups, the median score of males and females was 10 for all items. Within the DM-NP group, the median score of males was 10, whereas the median score of females was as follows: item 3 (median = 8); items 1, 2, 4, 5, 6, 9, 11 and 12 (median =10); items 7, 8, 10, 13 and 14 (median = 9). See Appendix 16 for a summary table of MFES data relative to gender among diabetics.

E. Results relative to part four of the study: Relationship between vibration scores, falls and fear of falling among diabetics

1. Relationship between vibration scores and falls

Falls and vibration scores

There was no relationship between number of reported falls and VPT scores among diabetics (rho=.24, p=.242) and within groups [DM-NPs (rho=.08, p=.806); DMs (rho=.48, p=.081)]. There was no significant relationship between falls and AS-VPT among diabetics (rho=.23, p=.26) and within groups [DM-NP (rho=.41, p=.187); DM (rho=.30, p=.296)]. There was no significant

relationship between falls and age among diabetics (rho=.08, p=.713) and within groups [DM-NP (rho=-.13, p=.679); DM (rho=.39, p=.174)]. There was no significant relationship between falls and VPT with age held constant among diabetics (T=.18, p>.05) and within groups [DM-NP (T=.07); DM (T=.29)].

There was no significant difference between fall category and vibration scores among diabetics [VPT (z=-1.448, p=.148); AS-VPT (z=-1.532, p=.126)]. Among high fallers, the average VPT and AS-VPT scores were 33.6 (±13.5) and 2.2 (±1.3), respectively. Among low fallers, the VPT and AS-VPT scores were 25.2 (±14.6) and 1.34 (±1.3), respectively. There was no difference in vibration scores between fall categories within the DM-NP group [VPT (z=-.649, p=.516); AS-VPT (z=-1.033, p=.302)], within the DM group [VPT (z=-1.486, p=.137); AS-VPT (z=-1.168, p=.243)]. See Appendix 17 for a summary table of fall group data among diabetics.

Falls, duration of diabetes and type of diabetes

The Fisher exact test indicated no association between fall category and type of diabetes (p>.05). The Mann Whitney U indicated no difference between fall category and duration of diabetes (z=-.927, p=.354).

Falls and strength

There was no significant relationship between falls and right or left plantarflexor strength among diabetics and within groups. There was no significant difference in plantarflexor strength between fall categories among

diabetics. There was a significant relationship between falls and right dorsiflexor strength among diabetics, but not within groups. There was no significant relationship between falls and left dorsiflexor strength among diabetics and within groups. There was no significant difference in dorsiflexor strength between fall categories among diabetics. See Appendix 5 for specific statistical test values and Appendix 17 for a summary table of fall group data among diabetics.

2. Relationship between vibration scores and fear

Results of the Mann Whitney U indicate no significant difference between fear groups and VPT scores among diabetics ($z=-1.439$, $p=.15$) and within groups [DM-NP ($z=-.733$, $p=.463$); DM ($z=-.778$, $p=.437$)]. Results of the Mann Whitney U indicate no significant difference between fear groups on AS-VPT scores among diabetics ($z=-1.0$, $p=.317$) and within groups [DM-NP ($z=-.244$, $p=.808$); DM ($z=-.645$, $p=.519$)]. Results of the Mann Whitney U indicate no significant difference in age between fear groups among diabetics ($z=-1.078$, $p=.464$) and within groups [DM-NP ($z=-.732$, $p=.464$); DM ($z=-.844$, $p=.399$)]. The results of the Fisher exact test indicate no association between gender and reported fear ($p=.096$). The results of the Mann Whitney U indicate no relationship between reported fear and duration of diabetes ($z=-.554$, $p=.580$). See Appendix 18 for a summary table of fear group data among diabetics.

F. Results relative to part five of the study: Relationship between functional balance performance, falls and fear of falling among diabetics

1. Falls and functional balance performance

Falls, BBS and TUG among diabetics

With fall outliers excluded, there was no significant relationship between BBS and reported falls (rho=-.37, p=.067) and between TUG and reported falls (rho=.31, p=.125). There was a significant relationship between number of reported falls and BBS item 8 scores (rho=-.40, p=.041) and item 12 scores (rho=-.43, p=.029), but not item 13 scores (rho=-.28, p=.177) and item 14 scores (rho=0.38, p=.056). The results of the Mann Whitney U indicated no significant difference between fall category and BBS performance (z=-1.909, p=.056) and TUG performance (z=-1.735, p=.083). The median BBS score was 50 (range 46-56) among high fallers and 55 (range 47-56) among low fallers. The average TUG score was 8.16 (± 1.2) among high fallers and 7.09 (± among low fallers).

There was a significant difference between fall category and scores on BBS item 8 scores (z=-2.068, p=.039), item 12 scores (z=-2.47, p=.014) and item 14 scores (z=-2.008, p=.048), but not item 13 scores (z=-1.263, p=.207). Among low fallers, the median score on BBS items 8, 12, 13 and 14 was 4. The range of scores among low fallers was as follows: item 8 = 3-4; item 12 = 2-4;

item 13 = 0-4; item 14 = 1-4. The average score among low fallers was as follows: item 8 = 3.8 (±.37); item 12 = 3.4 (±.5); item 13 = 3.1 (±1.43); item 14 = 3.1 (±1.1). Among high fallers, the median score on BBS items 8, 12 and 13 was 3, whereas the median score on BBS item 14 was 2. The range of scores among high fallers was as follows: item 8 = 3-4; item 12 = 3-4; item 13 = 1-4; item 14 = 1-4. The average score among high fallers was as follows: item 8 = 3.43 (±.53); item 12 = 3.0 (±1.15); item 13 = 2.4 (±1.4); item 14 = 2.0 (±1.25). See Appendix 17 for a summary table of fall group data among diabetics.

Falls and gender

Among diabetics, the percentage of males reporting falls (2/8 = 25%) was less than the percentage of females reporting falls (8/20 = 40%). With the 2 fall outliers excluded, the percentage of males reporting falls (1/7 = 14 %) was less than the percentage of females reporting falls (7/19 = 37%).

2. Relationship between fear and functional balance performance

Among diabetics, there was a significant difference between fear groups and performance on the BBS (z=-2.435, p=.015) and TUG (z=-3.334, p=.001). The median BBS score was 56 among participants in the "not fearful" group and 52 among participants in the "fearful" group. The average TUG score was 6.17 seconds (±1.2) among participants in the "not fearful" group and 8.6 (±1.7) among participants in the "fearful" group.

Among diabetics, the "fearful" group scored significantly lower on BBS items 8, 12 and 14 than the "not fearful" group. Results of the Mann Whitney U are as follows: item 8 (z=-3.035, p=.002), item 12 (z=-2.713, p=.007) and item 14 (z=-2.078, p=.038). There was no significant difference between fear groups in performance on BBS item 13 (z=-1.036, p=.3). There were an insufficient number of cases within the DM-NP and DM groups to analyze the difference between fear groups and performance on the BBS, TUG and BBS items. See Appendix 18 for a summary table of fear group data among diabetics.

3. Relationship between history of falls and fear of falling

Fear and falls

With the two falls outliers excluded, the average number of falls among diabetics reporting "not fearful" was 0.23 (±.6), whereas the average number of falls among diabetics reporting "fearful" was 1.5 (±1.9). With all diabetics analyzed together, the median number of falls reported by both fear groups was 0. Within groups, the average number of reported falls among those reporting "not fearful" were as follows: DM-NP=0.4 (±.89); DM= 0.13 (±0.35). Within groups, the average number of reported falls among those reporting "fearful" were as follows: DM-NP= 1.4 (±1.99); DM=1.67 (±1.97). Within the DM-NP group, the median number of falls was 0 for both fear groups. Within the DM

group, the median number of falls for those reporting "not fearful" and "fearful" was 0 and 1, respectively.

The results of the Mann Whitney U indicated no significant difference in number of reported falls between fear groups when analyzed among diabetics (z=-1.685, p=.092) and within groups [DM-NP (z=-.583, p=.560); DM (z=-1.701, p=.089)]. Greater than 20% of cells had an expected frequency < 5 in the chi square analysis on the association between fear group and fall category when analyzed among diabetics. The Fisher exact test indicated no association between fear group and fall category when analyzed among diabetics (p=.073). See Appendix 18 for a summary table of fear group data among diabetics. All raw data are included in table Appendix 19.

CHAPTER V: DISCUSSION

A. General characteristics of participants

The DM-NP, DM and control groups were similar in age, BMI and gender. All subjects scored at least a 22 on the MMSE, reasonably above the cut-off score. Data analysis on VPT and SWM confirms the neuropathic characteristic of the DM-NP group. The longer duration of diabetes in the DM-NP group compared to the DM group is consistent with results of longitudinal studies demonstrating a rise in neuropathy with duration of diabetes (Maser et al., 1989; Orchard et al., 1990). The significant differences in strength scores between DM-NPs and controls, but not between DM-NPs and DMs indicate the screening process successfully recruited diabetic groups differing primarily on somatosensory function. The significant negative relationship between ankle plantarflexor muscle strength and vibration scores among diabetics indicates the common simultaneous occurrence of motor and sensory neuropathic changes (Maser et al., 1989) among diabetics in the sample population. Although there were differences among groups on ROM of the right and left knee flexion and left metatarsal extension, ROM measurements for each participant were considered to be within functional limits for the tasks included in the dynamic balance tests. The strong correlation between performance on the TUG and BBS in the current study is not surprising, as both tests were developed to

measure dynamic balance performance. Studies using clinical balance tools to assess older adults report strong correlations among measures (Harada et al., 1995; Shumway-Cook, Gruber, et al., 1997).

B. Discussion relative to part one of the study: Relationship between diabetic neuropathy and functional balance performance among groups

1. General

In performance on the TUG, DM-NPs were significantly slower than controls, but there was no difference in performance between DM-NPs and DMs and between DMs and controls. On the TUG, diabetics were significantly slower than controls and DM-NPs were significantly slower than non-neuropathic participants. The BBS scores were significantly lower among DM-NPs than controls and among DMs than controls, but there was no significant difference between DM-NPs and DMs. The BBS scores were lower among diabetics than controls and among DM-NPs than non-neuropathic participants. There were significant differences among groups on BBS item 8 (DM-NPs performed more poorly than controls), BBS item 13 (DM-NPs and DMs performed more poorly than controls) and BBS item 14 (DM-NPs performed more poorly than DMs who performed more poorly than controls).

2. Performance on TUG

Braun et al. (1996) found no significant difference between healthy older diabetics and non-diabetics in performance on the TUG test. There are several differences between the Braun study and the current study. Braun did not test participants for neuropathy, but did state that 11 of the 61 diabetics (18%) and 26 of the 109 controls (14%) reported a feeling of numbness in the feet. Assuming no significant difference in vibration scores between the diabetics and controls tested in the Braun study, comparison of similar groups in the present study (the DM and control group) demonstrates consistent results.

The slower performance on the TUG by DM-NPs possibly indicates an influence of neuropathy on TUG performance. A study by Mueller et al. (1994) demonstrated that neuropathic diabetics walk with a slower velocity and shorter stride length than controls. The Mueller study did not compare the walking speeds of non-neuropathic diabetics to neuropathic diabetics, but it is possible that the non-neuropathic diabetics walk more slowly than controls, but more quickly than neuropathic diabetics. In the present study, the time to complete the TUG test among groups is consistent with this hypothesis. The result of no difference between the DMs and the control group, yet a difference between the DM-NPs and control group indicates the importance of neuropathy and not diabetes per se in performance among groups on the TUG test.

Another difference between the Braun study and the current study concerns the speed with which participants completed the TUG test. All groups in the present study were faster in performance of TUG [DM-NP = 8.03 (±2.1); DM=6.89 (±1.6); control=6.21 (±1.22)] than either group in the Braun study [diabetics = 14.7 (±6.2); controls 15.7 (±7.4)]. Participants in the current study were highly motivated to perform well on the test and required frequent reminders to walk and not run during the test. The mean age among diabetics and non-diabetics in the Braun study was 73 years (±7) and 75 years (± 8), respectively, whereas in the current study, the mean age among diabetics and non-diabetics was 52 (±11) and 51 (±10), respectively. It is possible that age could influence performance on TUG independent of diabetes and neuropathy. In the current study, there was no relationship between TUG and age when analyzed among diabetics and within groups. The author is not aware of a published study of TUG performance among various age groups.

It is possible that the finding of no difference between DM-NPs and DMs and between DMs and controls may be attributed to an inability of the TUG to detect balance differences in relatively healthy middle aged adults. Reliability and validity the TUG was established among community dwelling frail elderly with a variety of medical diagnoses, mobility skills and gait speeds (Podsiadlo & Richardson, 1991) and may not be sensitive to balance deficits, if present, among relatively healthy, younger individuals. The current study

indicates the TUG is sensitive to detecting differences among DM-NPs and controls, but a test including more challenging tasks may be necessary to detect dynamic balance deficits among DM-NPs and DMs.

3. Performance on BBS

The lower scores on the BBS between DM-NPs and controls, DMs and controls, diabetics and controls and DM-NPs and non-neuropathic participants indicates a possible influence of neuropathy and diabetes in task completion. However, the BBS did not significantly discriminate between DM-NPs and DMs, though the median BBS score was lower among DM-NPs compared to DMs. It is possible that the tasks included in the BBS are not sufficiently challenging to differentiate among DM-NPs and DMs. All participants scored the maximal possible score on 8 of the 14 BBS items (57%), indicating tasks included in the majority of items were not sufficiently challenging to discriminate among groups.

It should be noted that all participants in the current study scored between 46 and 56 on the BBS, above the score of 45 suggested as the cut-off score below which significant problems with ambulation in the elderly are evidenced (Berg, Wood-Dauphinee, et al., 1992). All participants in the current study were required to be independent ambulators. Although DM-NPs and DMs demonstrated the same range of scores on the BBS (46-56), the median scores

between the groups were quite different (DM-NP=52; DM=56) suggesting that neuropathy or some other unidentified characteristic may lead to lower scores on the BBS among independent ambulatory neuropathic diabetics.

4. Performance on BBS items

The results of the current study indicate that, relative to balance performance, response to BBS item 8 (stand and reach) may be useful in differentiating DM-NPs from controls, item 13 (tandem stance) may be useful in differentiating DM-NPs and DMs from controls, and response to item 14 (single leg stance) may be useful in differentiating all groups. Additional research is needed to examine the effect of diabetic neuropathy on dynamic balance performance, perhaps using tests incorporating tasks similar to those of BBS items 8, 13 and 14. For example, the FSR test requires participants to stand with feet parallel and reach forward with outstretched arms as far as possible while maintaining the base of support. The maximal distance reached is measured at shoulder height with a yardstick, tape measure or ruler. The functional reach test has demonstrated predictive validity in identifying elderly males subject to recurrent falls (Duncan et al., 1992). A timed single leg stance test has demonstrated predictive validity of injurious falls among community dwelling elders (Vellas et al., 1997).

C. Discussion relative to part two of the study: Relationship between vibration scores and functional balance performance among diabetics

Decreased vibration scores have been associated with poor clinical balance among the elderly (Lord et al., 1994), but the relationships between vibration scores and clinical balance performance among diabetics has not been reported in the literature. Results of this study demonstrate a strong significant relationship between vibration scores and BBS performance, but no relationship between vibration scores and TUG performance among diabetics. It is possible that the multi-task nature of the BBS may challenge the balance capabilities of diabetics more than the TUG. The relationship between vibration scores and BBS was maintained with strength of the ankle muscles held constant. The inter-correlation between BBS items, vibration scores and strength of the ankle muscles is demonstrated by a change in relationship between vibration scores and BBS items with strength of the ankle muscles held constant. Specifically, there was a significant relationship between vibration scores and BBS items 8 and 14. With strength of the plantarflexors held constant, the relationship included BBS items 13 and 14 and excluded item 8. With strength of the dorsiflexors held constant, the relationship between vibration scores and BBS items 8 and 14 was maintained and broadened to include item 13. These results

indicate a strong and unique relationship between vibration scores and BBS item 14, independent of the influence of ankle muscle strength.

A study by Daubney and Culham (1999) indicated that, among the community dwelling elderly (mean age in years= 75 $\pm$ 6.11), there is a significant relationship between the BBS and strength of the ankle dorsiflexors and evertors, measured by hand held dynamometry. In the current study, there was a strong relationship between BBS scores and strength of the ankle plantarflexors and a moderately strong relationship between BBS scores and strength of the dorsiflexors as determined by manual muscle testing among all participants and among diabetics. Strength of the ankle everters was not assessed in the current study.

It is possible that the reduced strength of the ankle muscles influenced performance on BBS items 8, 13 and 14. During testing, participants were allowed to stand with their preferred foot forward during performance of item 13 and to use their foot of choice for performance of BBS item 14. As no record was kept of the foot chosen for these activities, the specific influence of ankle strength on performance of BBS items 13 and 14 performance is not possible, though there was no statistically significant difference in strength scores between right and left sides. Strength measurements more definitive than allowed by manual muscle testing techniques may yield more insight into the relationship between strength and performance on the BBS and BBS items.

D. Discussion relative to part three of the study

The relationship between diabetic neuropathy, falls and fear of falling among groups

1. Relationship between diabetic neuropathy and history of falls

In the current study, there was no significant difference among groups on number of reported falls. There was no association between fall category and group membership.

These results differ from those of Richardson et al. (1992) who reported increased one-time falls and increased repetitive falls among persons with peripheral neuropathy including, but not limited to, neuropathy associated with diabetes. Richardson et al. hypothesized that postural hypotension may have contributed to the falls among the neuropathic diabetics in the study, although peripheral neuropathy remained as a risk factor for falls with data from these subjects excluded from the analysis. Falls information was collected via telephone interview and no data analysis was conducted with medications taken into account. Exclusion criteria in the current study not accounted for by the Richardson study included postural hypotension, musculoskeletal abnormalities, neuropathy associated with a condition other than diabetes, and medications associated with falling. The rigorous screening process of the current study limits comparison.

In the prospective study by Lord et al. (1994) on physiological factors associated with falls in elderly women, multiple falling was associated decreased vibration sense, as determined by a vibration device applied to the tibial tuberosity. Plantar surface vibration sense was not assessed. Information on falls was gathered in two-month increments by questionnaires and telephone interviews. It is possible that the prospective and regular nature of falls data collection in the Lord study led to a greater number of reported falls than would have occurred through recall one year later, as in the current study. A study by Cummings, Nevitt, and Kidd (1988) reported that the accuracy of recall of falls occurring over a 3-12 month period is poor among the elderly (> 60 years old), leading to an under-reporting of falls. Also, it is possible that differences in location of testing vibration sense contributed to conflicting results between the Lord study and the current study.

In a survey study by Cavanagh et al. (1992), Type 1 neuropathic diabetics were more likely to report an injurious fall occurring over the previous 4 years than non-neuropathic diabetics matched on gender, duration of diabetes, and vision ability. The actual number of falls (with and without injury) was not reported in the Cavanagh study.

Several differences exist between the Cavanagh study and the current study. The current study investigated the relationship between neuropathy and the number of reported falls in the past year, whereas the Cavanagh study

investigated the number of injurious falls (including falls in general, broken bones, sprains, cuts, and bruises) occurring over the previous 4 years, with injuries coded dichotomously as no occurrence of injury and occurrence of one or more injury. Cavanagh did not establish a cut-off vibration score for the determination of neuropathy, but rather defined the neuropathic group as diabetic participants with high vibration scores and the non-neuropathic group as diabetic participants with low vibration scores. The vibration scores were measured using a different testing device and vibration scores were reported in different units, compared to the current study. In the Cavanagh study, the average age of the participants was considerably younger [non-neuropathic=31.9 ($\pm$2.5); neuropathic = 32.9 ($\pm$2.5)] than in the current study [(DM=53.6($\pm$10.5); DM-NP=49.6 ($\pm$11.7)]. In the Cavanagh study, the average duration of diabetes was considerably longer [non-neuropathic=18.8 ($\pm$4.8); neuropathic= 22 ($\pm$4.6)] than in the current study [DM=8.6 ($\pm$6.5); DM-NP=15.9 ($\pm$10)]. Also, Cavanagh studied only Type 1 diabetics, whereas the majority of diabetic participants in the current study were Type 2 diabetics. In the current study, there was no significant relationship between type of diabetes and fall history, though this result should be taken with caution considering the small number of Type 1 diabetics in each group (DM-NP n=3; DM n=2).

The difference in findings of the current study and the Cavanagh study may be explained by differences among participants relative to age and duration

of diabetes, though the author found no published study of diabetics examining the relationship of age and duration of diabetes relative to falls. The differences in study design make it impossible to directly compare results of the current study to the Cavanagh study. Cavanagh hypothesized a potential under-reporting of injurious events, considering the retrospective interview method of data collection. However, it is also possible that over-reporting of events occurred, leading to inflated relationships reported in the study. One may assume, based on the results of the current study, that the one year retrospective fall history among DM-NPs and DMs is not significantly different. A prospective study including strict monitoring of fall occurrence is needed.

2. Relationship between diabetic neuropathy and fear of falling

In the current study, there was no difference in level of reported fear when analyzed among DM-NP, DM and control groups and when analyzed among DM-NPs and non-neuropathic participants. A higher level of fear was reported among diabetics than controls. There was no gender effect on reported fear. Controls reported a higher level of confidence than DM-NPs in performing the tasks of MFES items 2, 7 and 10. Males reported greater confidence than females on all MFES items when analyzed among all participants, among diabetics and within the DM-NP and DM groups. Within the control group, males reported greater than or equal confidence compared to females on all

MFES items except 1, 8 and 12.

The results of the current study differ from those reported by Cavanagh et al. (1992) of less perceived safety during walking between Type 1 neuropathic diabetics and non-neuropathic diabetics with duration of diabetes, gender and retinopathy scores statistically controlled. The result of less perceived safety among neuropathic diabetics in the Cavanagh study may be explained by the higher number of reported injurious falls among neuropathic diabetics compared to non-neuropathic diabetics. A high number of injurious falls could contribute to a higher level of fear, as fear of falling and previous falls are highly associated (Maki et al., 1990; Tinetti et al. 1994; Vellas et al, 1997). The higher degree of confidence expressed by males in the current study is consistent with the gender effect reported in Cavanagh (1992), though results should be taken with caution due to the small percentage of male participants in the current study.

E. Discussion relative to part four of the study: The relationship between vibration scores, falls and fear of falling among diabetics

1. Relationship between vibration scores and falls

In the current study, there was no significant relationship between vibration scores (VPT and AS-VPT) and number of reported falls among diabetics. There was no significant relationship between falls and age and between fall category and vibration scores among diabetics.

Lord et al. (1994) reported an association between poor vibration perception (measured at the tibial tuberosity) and multiple falls. Cavanagh et al. (1992) found no difference in mean neuropathy scores among neuropathic diabetic females reporting injury during walking and standing and those reporting no injury. In the current study, there was no relationship between multiple falls and vibration scores among diabetics. The lack of relationship between the physical impairment of decreased vibration sense and falls among diabetics is consistent with studies of the elderly indicating an unclear relationship between physical impairment and fall risk (Thorbahn & Newton, 1996). The progression of vibration perception deficit among diabetics may allow the adoption of strategies minimizing the risk of falling.

2. Relationship between vibration scores and fear of falling

Results of the current study indicate no association between vibration scores and fear of falling among diabetics. There was no gender effect on reported fear, but males did report greater confidence in performing the tasks on the MFES test. However, the results on gender should be considered with caution considering the small percentage of males in the study.

Cavanagh et al. (1992) reported a perception of decreased safety among neuropathic Type 1 diabetics, particularly females, but did not report the relationship between fear of falling and vibration scores among diabetics. Results of studies investigating fear of falling among the elderly consistently indicate an association between fear and previous falls (Vellas et al., 1997; Tinetti et al., 1988), but a clear association between physical impairment and fall risk has not been established (Thorbahn & Newton, 1996). The relationship between vibration scores, fear of falling and falls among diabetics warrants future study. It is suggested that future studies include the MFES and incorporate aggressive methods of data collection on fall history.

F. Discussion of results relative to part five of the study: Relationship between functional balance performance, falls and fear of falling among diabetics

1. Relationship between functional balance performance and falls

In the current study, there was no significant relationship between TUG or BBS and the number of reported falls among diabetics. Among diabetics, high fallers performed significantly more poorly on the BBS and BBS items 8, 12 and 14. High fallers performed more poorly on TUG, but not significantly.

The identification of fall risk factors is a difficult task, as many systems interact to achieve postural balance. The reported findings of studies on fall risk are not consistent regarding primary predictors (Maki et al, 1991; Nevitt et al,1989; Tinetti et al., 1988; Richardson et al., 1992), possibly due to various research designs (retrospective, prospective), groups (community dwellers, nursing home residents, frail elderly, healthy elderly), and balance assessments (postural sway, Tinetti, Berg, functional reach) included in the studies.

Studies of the elderly indicate the BBS cut-off score of ≥ 45 is highly specific, identifying persons not likely to fall (Thorbahn & Newton, 1996). In the current study, no participant scored lower than 46 on the BBS. Among diabetics, the BBS scores were lower for high fallers (median = 50) than low fallers (median = 55), but not significantly.

Shumway-Cook, Baldwin et al. (1997) demonstrated a non-linear relationship between decreasing BBS scores and increasing fall risk in community dwelling elders. An increased fall risk of 6-8% was associated with BBS scores in the range of 46-54. Maki et al. (1991) reported poorer scores on the Tinetti balance test among participants who fell one or more times in the previous year.

In the current study, participants scored the maximal score of 4 on the majority of BBS items. The lower scores of high fallers on BBS items 8, 12 and 14 suggest that a more objective assessment of performance on activities similar to these BBS items could potentially provide insight into fall prediction among diabetics.

2. Relationship between functional balance performance and fear of falling

In the current study, participants who reported "fearful of falling" performed significantly poorer on the BBS and TUG than participants who reported "not fearful" (among all participants and among diabetics). When all participants were analyzed, the "fearful" participants scored significantly lower on BBS items 8, 12, 13 and 14. When diabetics were analyzed, the "fearful" participants scored significantly lower on BBS items 8, 12 and 14.

Results of this study are consistent with those of Maki et al. (1991) who reported an association between scores on single leg stance and fear among independent ambulators aged 62-96 years. However, the result of significantly lower BBS scores and slower TUG speed in the "fearful" group in the current study among all participants and among diabetics are inconsistent with the finding by Maki et al (1997) of no association between fear and performance on the Tinetti Test, a balance test similar to the BBS, among elderly participants. Differences in age, neuropathic characteristics of participants and different measures of clinical balance performance may explain the differing results between studies.

3. Relationship between fear of falling and history of falls

There was no significant difference between the "fearful" and "not fearful" groups on number of reported falls when analyzed among all participants and among diabetics. There was no association between fall category and fear group among all participants and among diabetics.

These results are not consistent with studies of elderly community dwellers demonstrating an association between falls and fear of falling (Tinetti, et al., 1988; Vellas et al., 1997). It is possible that the elderly participants in the Vellas and Tinetti studies had a history of falling multiple times for several years, including the most recent year history included in the study. Multiple

falls over several years could lead to a greater fear of falling. It is possible that the neuropathic diabetics in the current study were aware of postural deficits and adopted compensatory gait changes, such as decreased walking speed and stride length and increased base of support. The gait modifications could lead to a more stable gait during daily activities, leading to fewer falls and subsequently less fear of falling. More research is needed to investigate the relationship between falls and fear of falling among diabetics.

G. Concluding remarks

1. Limitations

This study was limited to participants willing to volunteer and to participants who met the strict study inclusion criteria. It is possible that the participants in the study are not representative of a more general neuropathic diabetic, non-neuropathic diabetic and non-diabetic, non-neuropathic population. The influence of diabetes on the somatosensory, visual and vestibular systems could lead to a higher fall risk among diabetics who failed to meet study criteria. The prevalence of cardiovascular disease and medication use among diabetics could also render this population at risk of falls related to postural hypotension. Significant lower extremity weakness and musculoskeletal abnormalities could affect balance performance. The exclusion criteria of this study limited investigation of the impact of these abnormalities.

It is also possible that diabetics at highest risk of falling felt threatened by the study and chose not to participate, perhaps fearful of the revelation of balance deficits to others which could lead to decreased independence offered by companions or caregivers.

The sample size was limited, due to difficulty identifying diabetics meeting study criteria. The small sample size and data distributions limited the types of data analyses that could be responsibly performed.

The observational cross-sectional design of this study limits inference of causal relationships. Although the results indicate balance deficits among neuropathic diabetics, it is not possible to determine whether neuropathy causes balance problems or whether balance deficits among neuropathic diabetics are related to some other unidentified cause. It is not possible to determine whether fear causes poor performance on balance tests or whether recognition of poor balance causes one to be fearful.

The retrospective method of fall data collection was chosen to allow comparison with other fall studies utilizing a similar method. However, under-reporting of falls could have occurred. Although participants were required to describe the fall circumstances for each fall event to be counted in the study, it is also possible that participants over-reported falls to gain sympathy.

This study was designed to be clinical in nature. The tests and measures were chosen based on the reported validity and reliability, ease of use, time

required to administer the tests and availability of equipment. Isokinetic and hand-held dynamometry techniques of strength assessment are more discriminative and less subjective than the manual muscle testing technique employed in this study. However, many practitioners have limited access to these devices.

It is possible that some study participants failed to report their true level of fear to conceal their anxiety and others may have over-reported fear to gain attention. Also, although the questions related to fear were directly related to falls, the fear expressed by some participants may reflect a general state of anxiety not specifically related to falls.

Among the elderly, the BBS demonstrates good reliability, correlates highly with other balance measures and demonstrates high specificity relative to fall occurrence. In this study, the participants scored the highest score possible on the majority of BBS items, indicating the test may not be sufficiently challenging to unmask balance deficits among middle-aged, diabetic participants. Relationships between BBS items and falls, fear and other balance tests have not been routinely reported, although many balance tests include or limit tasks to those included in the BBS items.

2. Study conclusions

In this study, DM-NPs performed significantly more poorly on the TUG and BBS than controls. The DMs performed more poorly than controls on the TUG, though the finding was not statistically significant. There was a significant difference between DMs and controls in BBS performance. Performance on the TUG and BBS was not discriminatory between DM-NPs and DMs. Performance on BBS item 14 (single leg stance) was significantly different among all groups. Performance on TUG and BBS was not associated with number of reported falls and fall category (high and low fallers) among diabetics. Diabetics who reported multiple falls performed more poorly on BBS items 8, 12 and 14 than diabetics reporting one or no falls. There was no association between fear of falling and diabetic neuropathy, fall history and fall category. There was an association between fear and clinical balance performance among diabetics.

Among diabetics, there was a significant negative relationship between vibration scores and performance on the BBS. There was also a significant negative relationship between vibration scores and performance on BBS items 8 and 14. There was a negative relationship between vibration scores and BBS items 8 and 12 with strength of the ankle muscles held constant. There was no significant relationship between vibration scores and number of reported falls and no difference in vibration scores between high and low fallers. There was

no significant difference in vibration scores and fear groups. There was a significant difference between fear groups and performance on TUG and BBS.

3. Implications

The difference in performance on the TUG and BBS between DM-NPs and controls and between DM-NPs and non-neuropathic participants may indicate a difference in dynamic balance performance relative to diabetic neuropathy and not to diabetes per se. The finding of no difference between DM-NPs and DMs on TUG and BBS performance may be due to a lack of sensitivity of these tests to detect balance deficits among diabetics. It is also possible that diabetics develop compensatory strategies allowing them to walk with remarkable balance, even in the presence of varying degrees of neuropathy. More challenging balance activities than those included in the TUG and BBS may be necessary to unmask balance deficits among diabetics. The significant difference among groups on BBS item 14 indicates a potential usefulness in differentiating balance deficits among diabetics.

The increased injurious fall risk among neuropathic diabetics suggested by other researchers may be related to factors other than those apparent in the BBS and TUG tests. The ability of BBS items to differentiate between high and low fallers among diabetics may prove useful in identifying diabetics at risk for falls. It is possible that diabetics experience fewer falls than the elderly and thus

have less fear of falling. It is also possible that diabetics develop compensatory strategies that make them less likely to fall. Fear of falling should be considered in studies of dynamic balance and falls among diabetics.

4. Suggestions for future research

A dynamic balance test battery for diabetics including the more challenging items of the BBS should be developed. Single leg stance, tandem stance and stool stepping activities should be included along with timed gait tests with measurement of stride and step length. Additional dynamic balance tests, such as the FSR, TBGS, BSPT and DGI should be evaluated among diabetics. Strength measures, including manual muscle testing and isokinetic testing should be included. Prospective studies of falls with close monitoring of participants may lead to a more accurate report of falls than retrospective data collection. Future studies should direct questions related to fear with each balance testing procedure, rather than asking global questions related to fear and falls. Such distinctions would allow the determination of whether fear and poorer performance were related to balance deficits or an overall sense of anxiety not specific to falls or balance performance. The relationships between static balance, as measured by postural sway, dynamic posturography and functional balance performance among diabetics should be explored.

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APPENDICES

Appendix 1: List of Abbreviations

AS-VPT = age standardized vibration perception threshold

BBS = Berg Balance Scale

BBS item(s) = item(s) on the Berg Balance Scale

BSPT = Balance Self-Perceptions Test

DGI = Dynamic Gait Index

DM = non-neuropathic diabetics

DM-NP = neuropathic diabetics

FSR = Functional Stand and Reach

MFES = Modified Falls Efficacy Scale

MMSE = Mini Mental State Exam

Rho = Spearman rank order coefficient

ROM = range of motion

SWM = Semmes-Weinstein monofilaments

TBGS = Tinetti Balance and Gait Score

TUG = Timed Up & Go test

Appendix 2: Modified Falls Efficacy Scale

*Taken from: Hill KD, Schwarz JA, Kalogeropoulos AJ, Gibson SJ. Fear of falling revisited. *Arch Phys Med Rehabil* 1996;77:1025-1029]

Item 1: get dressed and undressed

Item 2: prepare a simple meal

Item 3: take a bath or shower

Item 4: get in/out of a chair

Item 5: get in/out of bed

Item 6: answer the door or telephone

Item 7: walk around inside of your house

Item 8: reach into cabinets or closets

Item 9: light house keeping

Item 10: simple shopping

Item 11: using public transportation

Item 12: crossing roads

Item 13: light gardening or hanging out the wash

Item 14: using front or rear steps at home

[Participants are asked "How confident/sure are you that you do each of the activities without falling?." Participants rate all items on a scale from 0-10 (0=not confident at all; 5=fairly confident; 10=completely confident)].

Appendix 3: Berg Balance Scale Items*

*[Taken from: Lewis CB, McNerney T. *Clinical Measures of Functional Outcomes: "The Functional Outcomes Toolbox."* McLean, VA:Learn Publications: 1997]

Item 1: Sitting to standing

Item 2: Standing unsupported

Item 3: Sitting with back unsupported but feet supported on floor or on a stool

Item 4: Standing to sitting

Item 5: Transfers

Item 6: Standing unsupported with eyes closed

Item 7: Standing unsupported with feet together

Item 8: Reaching forward with outstretched arm while standing

Item 9: Pick up object from the floor from a standing position

Item 10: Turning to look behind over left and right shoulders while standing

Item 11: Turn 360 degrees

Item 12: Place alternative foot on step or stool while standing unsupported

Item 13: Standing unsupported one foot in front

Item 14: Standing on one leg

Appendix 4: Summary Table of Participant characteristics

	DM-NP (N=14)	DM (N=14)	Control (N=14)
Age *(years)*	49.6 (11.7) [48; 32-69]	53.6 (10.5) [55; 31-67]	51.1(9.5) [51; 36-68]
Gender *(male/female)*	4/10	4/10	3/11
BMI *(kg/m^2)*	29.3 (6.7) [27.5; 19.7-40]	33.2 (6.4) [31.9; 23.4-45.7]	28.5(5.8) [28.5; 20.6-43.7]
Type of diabetes *(Type 1/Type 2)*	3/11	2/13	n/a
Duration of diabetes *(years)* {a}	15.9 (10.0) [17; 3-34]	8.6 (6.5) [8; 1-20]	n/a
MMSE {c}	[28; 25-30]	[28; 22-30]	[29; 26-29]
VPT *(volts)* {a, b}	40.43 (10.62) [44.5; 21-50+]	17.0 (6.82) [16.25; 7-31]	11.93 (4.8) [10.75; 5-23.5]
AS-VPT *(z scores)* {a, b, c^1}	2.82 (0.57) [2.8; 2-3.68]	0.48 (0.72) [0.45; -1.1-1.44]	-0.29 (0.82) [-0.29; -1.55-1.17]
SWM {a, b}	5.28 (0.89) [5.06; 3.96-6.65+]	4.2 (0.72) [3.9; 3.61-5.99]	3.77 (0.25) [3.72; 3.22-4.17]

1. Data are reported as mean (standard deviation) [median; range], except as otherwise indicated; italics describe units/description reported
2. n/a = not applicable
3. codes for significance, indicated in { } after variable (determined by Mann Whitney U), unless otherwise indicated below:
   - a= significant difference between DM-NP and DM
   - b = significant difference between DM-NP and control
   - c = significant difference between DM and control
   - c^1= significant difference between DM and control by Mann Whitney U, but not ADMR
   - d = significant difference between diabetics and controls
   - e = significant difference between DM-NP and non-neuropathic participants

Appendix 5: Statistical test values

Variable	Statistical Data
Age	3 groups: F=.525, p=.596; x^2=1.099, p=.577
BMI	3 groups: F=2.253, p=.119; x^2=4.512, p=.105
Duration diabetes	DM-NP & DM: t=-2.309, p=.029; z=-2.049, p=.041
MMSE	3 groups:x^2=9.516, p=.009 DM-NP & DM: z=-1.278, p=.201 DM-NP & control: z=-1.882, p=.06 DM & control: z=-2.801, p=.005
ROM: right hip flexion	3 groups: F=2.960, p=.064; x^2=4.624, p=.099
ROM: left hip flexion	3 groups:F=3.542, p=.039; x^2= 5.933, p=.051
ROM: right knee flexion	3 groups: F=15.885, p=.001; x^2=19.544, p=.000 DM-NP & DM: z=-1.07, p=.287 DM-NP & control: z=-3.237, p=.001 DM & control: z=-4.169, p=.00
ROM: left knee flexion	3 groups: F=9.129, p=.001; x^2=14.442, p=.001 DM-NP & DM: z=-.467, p=.641 DM-NP & control: z=1.528, p=.126 DM & control: z=1.372, p=.00
ROM: right metatarsal extension	3 groups: F=2.761, p=.076; x^2=4.889, p=.087
ROM: left metatarsal extension	3 groups:F=4.459, p=.018; x^2=8.013, p=.018 DM-NP & DM:z=-.972, p=.331 DM-NP & control: z=-2.228, p=.026 DM & control: z=-2.486, p=.016
strength: right PF	3 groups: F=5.595, p=.007; x^2=9.141,p=.01 DM-NP & DM: z=-1.856, p=.063 DM-NP & control: z=-2.886, p=.004 DM & control: z=-1.242, p=.214
strength: left ankle PF	3 groups: F=5.746, p=.007; x^2= 9.347, p=.009 DM-NP & DM: z=1.485, p=.138 DM-NP & control: z=-3.105, p=.002 DM & control: z=-1.455, p=.146
strength: right toe flexion	3 groups: F=6. 877, p=.003; x^2=10..981, p=.004 DM-NP & DM: z=-1.577, p=.115 DM-NP & control: z=-3.241, p=.001 DM & control: z=-2.117, p=.034
strength: left toe flexion	3 groups: F =7.239, p=.002; x^2=11..224, p=.004 DM-NP & DM: z=-1.674, p=.094 DM-NP & control: z=-3.236, p=.001 DM & control: z=-2.117, p-.034

Appendix 5: (continued)

strength: right toe extension	3 groups: F=7..233, p=.001; x^2=11.169, p=.004 DM-NP & DM: z=-1.651, p=.099 DM-NP & control: z=-3.24, p=.001 DM & control: z=-2.117, p=.034
strength left toe extension	3 groups: F=7.233, p=.002; x^2=11.169, p=.004 DM-NP & DM: z=-1.651, p=.099 DM-NP & control: z=-3.24, p=.001 DM & control: z=-2.117, p-.034
VPT	3 groups: F=53.254, p=.00; x^2=27.267, p=.00 DM-NP & DM: z=-4.143, p=.00 DM-NP & control: z=-4.462, p=.00 DM & control: z=-2.117, p=.034
AS-VPT	3 groups: F=7.33, p=.00; x^2=30.278, p=.00 DM-NP & DM: z=-4.503, p=.00 DM-NP & control: z=-4.503, p=.00 DM & control: z=-2.551, p=.011
SWM	3 groups: x^2=21.046, p=.00 DM-NP & DM: z=-3.197, p=.001 DM-NP & control: z=-4.218, p=.00 DM & control: z=-1.839, p=.066
TUG	3 groups: F=4.228, p=.022; x^2=6.515, p=.038 DM-NP & DM: z=-1.379, p=.168 DM-NP & control: z=-2.527, p=.011 DM & control: z=-1.172, p=.241 Diabetics & controls: z=-2.148, p=.032 DM-NPs & non-NPs: z=-2.268, p=.023
BBS	3 groups: x^2=19.09, p=.00 DM-NP & DM: z=-2.146, p=.032 DM-NP & control: z=-4.284, p=.00 DM & control: z=-2.691, p=.007 Diabetics & controls: z=-3.731, p=.00 DM-NPs & non-NPs: z=-3.834, p=.00
BBS 8	3 groups: x^2=6.359, p=.042 DM-NP & DM: z=-1.286, p=.199 DM-NP & control: z=-2.2423, p=.015 DM & control: z=-1.441, p=.15 Diabetics & controls: z=-2.025, p=.043 DM-NP & nonNP: z=-2.314, p=.021
BBS 12	3 groups: x^2= 4.389, p=.111 Diabetics & controls: z=-2.016, p=.044 DM-NP & nonNP: z=-1.502, p=.133
BBS 13	3 groups: x^2=8.819, p=.012 DM-NP & DM: z=-.894, p=.371 DM-NP & control: z=-2.964, p=.009 DM & control: z=-2.409, p=.016 Diabetics & controls: z=-2.814, p=.005 DM-NP & non-NP: z=-2.228, p=.026

Appendix 5: (continued)

BBS 14	3 groups: x^2=18.491, p=.00 DM-NP & DM: z=-2.519, p=.012 DM-NP & control: z=-4.034, p=.00 DM & control: z=-2.411, p=.016 Diabetics & controls: z=-3.436, p=.001 DM-NP & non-NP: z=-3.957, p=.00
Falls	3 groups: F=.616, p=.546; x^2=.367, p=.832 Diabetics & controls: z=-.491, p=.624 DM-NP & non-NP: z=-.547, p=.584
MFES 2	3 groups: x^2=7.149, p=.028 DM-NP & DM: z=-1.72, p=.085 DM-NP & control: z=-2.294, p=.022 DM & control: z=-1.0, p=.32 Diabetics & controls: z=-2.829, p=.005 DM-NP & non-NP: z=-2.62, p=.009
MFES 3	3 groups: x^2= 3.775, p=.151 Diabetics & controls: z=-2.549, p=.011 DM-NP & non-NP: z=-1.925, p=.054
MFES 4	3 groups: x^2= 5.177, p=.075 Diabetics & controls: z=-2.22, p=.026 DM-NP & non-NP: z=-1.996, p=.046
MFES 7	3 groups: x^2=6.79, p=.034 DM-NP & DM: z=-1.186, p=.235 DM-NP & control: z=-2.620, p=.009 DM & control: z=-1.44, p=.15 Diabetics & controls: z=-2.493, p=.013 DM-NPs & non-NP: z=-2.363, =.018
MFES 9	3 groups: x^2= 5.678, p=.058 Diabetics & controls: z=-2.405, p=.016 DM-NPs & non-NPS: z=-2.162, p=.031
MFES 10	3 groups: x^2=6.473, p=.039 DM-NP & DM: z=-.914, p=.361 DM-NP & control: z=-2.18, p=.009 DM & control: z=-1.8, p=.072 Diabetics & controls: z=-2.214, p=.027 DM-NPs & non-NPs: z=-2.093, p=.036
MFES 13	3 groups: x^2= 3.384, p=.184 Diabetics & controls: z=-1.965, p=.049 DM-NP & non-NP: z=-1.817, p=.069

Appendix 6: Summary Table of ROM Data Among Groups

	DM-NP	DM	Control
Right hip flexion	119.79 (6.2)	118.5 (5.4)	114.9 (5.1)
Left hip flexion	120.9 (6.7)	120.1 (5.4)	115.4 (5.6)
Right knee flexion {b,c}	123 (10.2)	119.5 (6.3)	135.6 (6.9)
Left knee flexion {c}	126.2 (10.1)	122.9 (5.6)	135.3 (7.4)
Right ankle dorsiflexion	10.9 (1.9)	10.7 (1.5)	10.4 (3.0)
Left ankle dorsiflexion	11.2 (1.8)	11.5 (2.1)	10.9 (2.8)
Right first metatarsal extension	56.4 (6.9)	55.7 (8.1)	61.1 (4.0)
Left first metatarsal extension {c}	56.4 (5.0)	54.3 (7.8)	61.1 (5.3)

1. Data are means (standard deviation) in degrees as measured by standard goniometer
2. Codes for significance, indicated in { } after variable (determined by Mann Whitney U):
   a = significant difference between DM-NP and DM
   b = significant difference between DM-NP and control
   c = significant difference between DM and control

Appendix 7: Summary Table of Strength Data Among Groups

	DM-NP	DM	Control
Right knee extension	4.9 (0.36) [5; 4-5]	4.9 (0.36) [5; 4-5]	5 [5]
Left knee extension	4.8 (0.43) [5; 4-5]	4.9 (0.36) [5; 4-5]	5 [5]
Right ankle plantarflexion {b}	4.1 (0.63) [4; 3.5-5]	4.6 (0.62) [5; 3.5-5]	4.8 (0.46) [5; 3.5-5]
Left ankle plantarflexion {b}	4.1 (0.6) [4; 3.5-5]	4.5 (0.66) [5; 3.5-5]	4.9 (0.36) [5; 4-5]
Right ankle dorsiflexion	4.7 (0.47) [5; 4-5]	4.9 (0.36) [5; 4-5]	4.9 (0.27) [5; 4-5]
Left ankle dorsiflexion	4.7 (0.47) [5; 4-5]	4.8 (0.43) [5; 4-5]	4.9 (0.27) [5; 4-5]
Right toe flexion {b}	4.3 (0.64) [4; 3.5-5]	4.7 (0.54) [5; 3.5-5]	5 [5]
Left toe flexion {b}	4.3 (0.67) [4; 3.5-5]	4.7 (0.54) [5; 3.5-5]	5 [5]
Right toe extension {b}	4.3 (0.67) [4; 3.5-5]	4.7 (0.54) [5; 3.5-5]	5 [5]
Left toe extension {b}	4.3 (0.67) [4; 3.5-5]	4.7 (0.54) [5; 3.5-5]	5 [5]

1. Data are means (standard deviation) [median; range] as determined by manual muscle test
2. Codes for significance, indicated in { } after variable (determined by Mann Whitney U):

   a = significant difference between DM-NP and DM

   b = significant difference between DM-NP and control

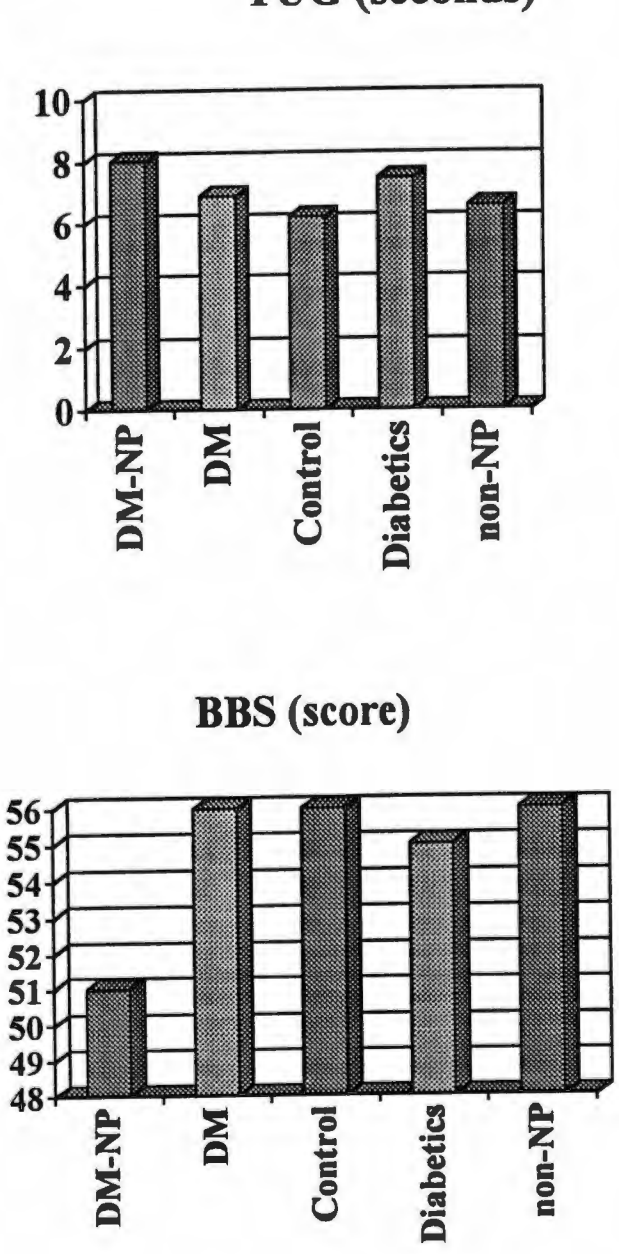
   c = significant difference between DM and control

Appendix 8: Summary Table of Balance Scores Among Groups

	DM-NP	DM	Control	Diabetics	Non-NP
TUG {b,d,e}	8.03 (2.09) [7.69; 4.75-12.65]	6.89 (1.6) [6.28; 4.42-10.08]	6.21 (1.22) [5.6; 4.9-8.52]	7.46 (1.92) [7.4; 4.42-12.65]	6.55 (1.44) [6.3; 4.42-10.08]
BBS {b,c,d,e}	[51; 46-56]	[56; 46-56]	[56]	52.9 (3.4) [54.5; 46-56]	55 (2.23) [56; 46-56]
BBS item 8 {b, d, e}	[4 ; 3-4]	[4; 3-4]	[4]	3.75 (.44) [4; 3-4]	3.93 (.26) [4; 3-4]
BBS item 12 {d}	[4; 1-4]	[4; 2-4]	[4]	3.6 (.79) [4; 1-4]	3.86 (.45) [4; 2-4]
BBS item 13 {b,c,d, e}	[3.5; 0-4]	[4; 0-4]	[4]	2.96 (1.4) [4; 0-4]	3.6 (.99) [4; 0-4]
BBS item 14 {a, b, c, d, e}	[2; 1-4]	[4; 1-4]	[4]	2.86 (1.2) [3; 1-4]	3.71 (.71) [4; 1-4]

1. Data are reported as mean (standard deviation) [median; {range}]
2. Non-NP = non-neuropathic participants
3. Codes for significance, indicated in { } after variable (determined by Mann Whitney U:
   - a = significant difference between DM-NP and DM
   - b = significant difference between DM-NP and control
   - c = significant difference between DM and control
   - d = significant difference between diabetics and controls
   - e = significant difference between DM-NP and non-neuropathic participants
4. All participants in the control group scored the maximum possible on all BBS items

Appendix 9: Graphical representation of balance test results



Appendix 10: Summary Table of Scores on BBS items

	item 6	item 8	item 9	item 12	item 13	item 14
DM-NP	3 (1) 4 (13)	3 (5) 4 (9)	3 (1) 4 (13)	1 (1) 2 (1) 3 (2) 4 (10)	0 (1) 1 (3) 2 (2) 3 (1) 4 (7)	1 (5) 2 (3) 3(3) 4 (3)
DM	4 (14)	3 (2) 4 (12)	3 (1) 4 (13)	2 (1) 3 (2) 4 (11)	0 (1) 1 (1) 2 (1) 3 (2) 4 (9)	1 (1) 2 (1) 3 (3) 4 (9)

Data are scores (frequency)

Appendix 11: Summary Table of Critical Correlations Among Diabetics

	VPT	AS-VPT	TUG	BBS	Falls
Age	.20	-.17	.36	-.29	.08
Duration of diabetes	.34	.42*	-.26	.07	.17
Falls	.24	.23	.31	-.37	--
TUG	.34	.26	--	-.78*	.31
BBS	-.64*	-.57*	-.78*	--	-.37
strength right plantarflexors	-.44*	-.39*	-.60*	.61*	-.07
strength left plantarflexors	-.39*	-.33	-.68*	.64*	-.07
strength right dorsiflexors	-.27	-.27	-.50*	-.51*	-.40*
strength left dorsiflexors	-.13	-.12	-.47*	.39*	-.31

1. Data are Spearman rho correlation coefficients
2. * = significant relationship

Appendix 12: Summary Table of Partial Correlations Among Diabetics

	Age constant	strength right PF constant	strength left PF constant	strength right DF constant	strength left DF constant
Duration of diabetes * VPT	.22				
Duration of diabetes * AS-VPT	.28*				
TUG * VPT	.15				
TUG * AS-VPT	.19				
BBS * VPT	-.45*				
BBS * AS-VPT	-.44*				
BBS *VPT		-.35*	-.29*	-.42*	-.46*
BBS * AS-VPT		-.32*	-.34*	-.49*	-.40*
BBS 8 * VPT		-.25	-.26	-.36*	-.45*
BBS 12 * VPT		-.14	-.12	-.16	-.21
BBS 13 * VPT		-.35*	-.37*	-.43*	-.45*
BBS 14 * VPT		-.56*	-.57*	-.64*	-.66*
Falls * VPT	.18				

1. Data are Kendall's tau b partial correlations
2. * = significant relationhship
3. Empty cells = analysis not conducted

Appendix 13: Summary Table of Correlations With BBS items Among Diabetics

	BBS item 8	BBS item 12	BBS item 13	BBS item 14
VPT	-.33*	-.22	-.35	-.65*
AS-VPT	-.35	-.21	-.25	-.65*
Strength right plantarflexors	.36	.33	.43*	.51*
Strength left plantarflexors	.36	.40*	.43*	.51*
Strength right dorsiflexors	.70*	.32	.25	.52*
Strength left dorsiflexors	.62*	.26	.17	.41*

1. Data are Spearman rho correlation coefficients
2. * = significant relationship

Appendix 14: Summary Table of Falls and Fear Among Groups

	DM-NP	DM	Control
Falls	1.0 (1.65) [0; 0-5]	0.79 (1.48) [0; 0-4]	0.43 (0.76) [0; 0-2]
Percentage of participants reporting falls	29%	21%	14%
"Not fearful" group *(number of participants)*	N=5	N=8	N=12
"Fearful" group *(number of participants)*	N=7	N=6	N=2
MFES	Mean male score > mean female score on all items	mean male score > mean female score on all items	mean male score ≥ mean female score on all items except 1,8, 12
Falls among "not fearful"	0.4 (.89) [0; 0-2]	0.125 (0.35) [0; 0-1]	0.5 (0.8) [0; 0-2]
Falls among "fearful"	1.43 (1.99) [0; 0-5]	1.67 (1.97) [0; 0-4]	n/a

1. Data are reported as mean (standard deviation) [median; {range}], except as otherwise indicated
2. There were no significant differences among groups on falls and fear

Appendix 15: Summary Table of MFES Data Among Groups

	DM-NP	DM	Control
MFES 1	9.4 (1.7) [10; 4-10]	9.7 (0.8) [10; 7-10]	9.9 (0.3) [10; 9-10]
MFES 2 {b}	8.8 (2.0) [10; 5-10]	9.9 (0.5) [10; 8-10]	10 (0) [10]
MFES 3	8.4 (2.6) [10; 1-10]	9.7 (0.7) [10; 8-10]	9.7 (0.6) [10; 8-10]
MFES 4	9.3 (1.2) [10; 7-10]	9.5 (1.4) [10; 5-10]	10 (0) [10]
MFES 5	9.7 (0.65) [10; 8-10]	9.8 (0.6) [10; 8-10]	10 (0) [10]
MFES 6	9.8 (0.6) [10; 8-10]	9.9 (0.5) [10; 8-10]	10 (0) [10]
MFES 7 {b}	9.3 (0.98) [10; 7-10]	9.4 (1.6) [10; 5-10]	10 (0) [10]
MFES 8	9.3 (1.1) [10; 7-10]	9.8 (0.8) [10; 7-10]	9.9 (0.36) [10; 9-10]
MFES 9	9.1 (1.4) [10; 6-10]	9.7 (0.83) [10; 7-10]	10 (0) [10]
MFES 10 {b}	8.8 (1.9) [10; 5-10]	9.1 (2.0) [10; 4-10]	10 (0) [10]
MFES 11	8.2 (3.2) [10; 1-10]	9.0 (2.1) [10; 4-10]	9.9 (0.53) [10; 8-10]
MFES 12	7.9 (3.6) [10; 1-10]	9.0 (2.1) [10; 4-10]	9.8 (0.58) [10; 8-10]
MFES 13	8.5 (2.2) [10; 4-10]	8.8 (3.1) [10; 0-10]	9.9 (0.36) [10; 9-10]
MFES 14	8.2 (3.1) [10; 1-10]	8.4 (3.2) [10; 0-10]	9.9 (0.53) [10; 8-10]

1. Data are reported as mean (standard deviation) [median; {range}]
2. Codes for significance, indicated in { } after variable (determined by Mann Whitney U:
   - a = significant difference between DM-NP and DM
   - b = significant difference between DM-NP and control
   - c = significant difference between DM and control
   - d = significant difference between diabetics and controls
   - e = significant difference between DM-NP and non-neuropathic participants

Appendix 16: Summary Table of MFES Items Between Males and Females Among Diabetics

	Males (N=7)	Females (N=19)
MFES 1	9.9 (0.38) [10; 9-10]	9.5 (1.5) [10; 4-10]
MFES 2	10 (0) [10]	9.2 (1.7) [10; 5-10]
MFES 3	10 (0) [10]	8.8 (2.2) [10; 1-10]
MFES 4	10 (0) [10]	9.2 (1.4) [10; 5-10]
MFES 5	10 (0) [10]	9.6 (0.7) [10; 8-10]
MFES 6	10 (0) [10]	9.7 (0.65) [10; 8-10]
MFES 7	10 (0) [10]	9.1 (1.5) [10; 5-10]
MFES 8	10 (0) [10]	9.4 (1.1) [10; 7-10]
MFES 9	10 (0) [10]	9.2 (1.3) [10; 6-10]
MFES 10	10 (0) [10]	8.6 (2.1) [10; 4-10]
MFES 11	10 (0) [10]	8.1 (3.0) [10; 1-10]
MFES 12	10 (0) [10]	7.95 (3.2) [10; 1-10]
MFES 13	10 (0) [10]	8.2 (3.0) [10; 0-10]
MFES 14	10 (0) [10]	7.6 (3.5) [10; 0-10]

Data are reported as mean (standard deviation) [median; {range}]

Appendix 17: Summary Table of Fall Group Data Among Diabetics

	Low falls (0 or 1 fall)	High falls (≥ 2 falls)
TUG	7.09 (2.05) [6.3; 4.42-12.65]	8.16 (1.2) [8.1; 6.26-10.1]
BBS	[55; 46-56]	[50; 47-56]
BBS 8 {*}	[4; 3-4]	[3; 3-4]
BBS 12 (*)	[4; 2-4]	[3; 3-4]
BBS 13	[4; 0-4]	[3; 1-4]
BBS 14 {*}	[4; 1-4]	[2; 1-4]
VPT	25.2 (14.6) [21; 7-50+]	33.6 (13.5) [31; 15-49.5]
AS-VPT	1.34 (1.3) [1.06; -1.1-3.68]	2.2 (1.3) [2.6; 0.25-3.53]
Strength right plantarflexors	4.4 (0.69) [5; 3.5-5]	4.2 (0.57) [4; 3.5-5]
Strength left plantarflexors	4.4 (0.69) [5; 3.5-5]	4.2 (0.57) [4; 3.5-5]
Strength right dorsiflexors	4.9 (0.32) [5; 4-5]	4.6 (0.53) [5; 4-5]
Strength left dorsiflexors	4.8 (0.37) [5; 4-5]	4.6 (0.53) [5; 4-5]

1. Data are reported as mean (standard deviation) [median; {range}]
2. {*} = significant difference

Appendix 18: Summary Table of Fear Group Data Among Diabetics

	"Not fearful"	"Fearful"
BBS {*}	[56; 49-56]	[52; 46-56]
TUG {*}	6.17 (1.2) [6.24; 4.42-8.43]	8.6 (1.7) [8.3; 6.22-12.65]
BBS 8 {*}	[4; 4]	[3; 3-4]
BBS 12 {*}	[4; 4]	[4; 1-4]
BBS 13	[4; 0-4]	[3; 0-4]
BBS 14 {*}	[4; 1-4]	[2; 1-4]
VPT	23.7 (13.8) [21; 7-50+]	31.23 (14.8) [31; 8.5-50+]
AS-VPT	1.34 (1.31) [0.92; -0.25-3.53]	1.81 (1.44) [1.87; -1.1-3.68]
Falls	0.23 (0.60) [0; 0-2]	1.54 (1.9) [0; 0-5]
Age	49 (11.79) [49; 31-67]	53.1 (10.73) [55; 32-69]
Duration of diabetes *(in years)*	13.2 (9.7) [9; 4-34]	11.5 (8.9) [9; 1-30]
Gender *(% males : % females)*	86 : 37	14 : 63

1. Data are reported as mean (standard deviation) [median; {range}], unless otherwise indicated
2. {*} = significant difference

Appendix 19: Raw Data

subject	group	age	VPT	AS-VPT	SW	typediabetes	durationdiabetes
4	1	42	24.5	2.24	4.62	2	9
7	1	45	50	3.68	6.65	1	30
12	1	61	50	2.85	4.96	2	6
14	1	64	40	2.05	4.93	2	3
1	1	32	31	3.31	5.13	2	5
2	1	34	21	2.16	3.96	1	28
3	1	37	24.5	2.53	5.32	2	6
5	1	44	41.5	3.23	6.28	2	17
6	1	44	47	3.53	4.84	1	34
8	1	50	49.5	3.38	5.13	2	22
9	1	54	50	3.13	6.45	2	19
10	1	58	48	2.76	6.65	2	17
11	1	60	45	2.6	5	2	18
16	1	69	44	2	4.08	2	9
21	2	52	17.5	0.9	3.72	2	4
22	2	55	21	1.06	3.84	2	8
26	2	56	12.5	-0.18	3.72	1	20
30	2	66	21.5	0.56	4.31	2	10
17	2	31	7	-0.25	4.02	2	4
18	2	36	12.5	0.92	3.61	1	19
19	2	47	11.5	0.17	4.24	2	1
20	2	49	12.5	0.09	3.61	2	4
23	2	55	24.5	1.43	5.46	2	1
24	2	55	8.5	-1.1	4.75	2	9
28	2	57	15	0.25	3.96	2	15
29	2	58	23.5	1.05	5.99	2	15
31	2	67	31	1.44	3.72	2	2
32	2	67	19.5	0.33	3.84	2	8
35	3	43	9.5	-0.29	3.72	0	0
39	3	50	10.5	-0.32	4.08	0	0
40	3	51	11	-0.21	3.72	0	0
33	3	36	10.5	0.5	3.72	0	0
34	3	38	5	-1.55	3.22	0	0
36	3	44	17.5	1.17	3.61	0	0
37	3	47	9.5	-0.29	4.17	0	0
38	3	48	6.5	-1.47	3.61	0	0
41	3	53	13	-0.09	3.84	0	0
42	3	55	15	0.25	3.96	0	0
44	3	58	11	-0.76	3.61	0	0
46	3	59	8.5	-1.38	3.61	0	0
47	3	66	23.5	0.78	4.13	0	0
48	3	68	16	-0.42	3.72	0	0

Appendix 19: (continued)

gender	BBS	TUG	falls	fallcategory	bmi	mmse	fearfal	fearcategory
male	56	5.62	0	low	21.3	28	1	1
male	55	6.22	0	low	31.02	27	2	2
male	49	7.51	0	low	40.01	25	1	1
male	54	10.3	12	high	26.51	27	2	2
female	48	10.1	5	high	19.69	27	2	2
female	56	4.75	0	low	25.95	28	1	1
female	46	12.7	0	low	37.02	29	2	2
female	55	6.87	0	low	28.45	29	1	1
female	50	7.6	2	high	25.16	29	1	1
female	47	7.77	2	high	22.11	28	2	2
female	55	6.82	7	high	31.76	27	3	2
female	50	7.94	0	low	39.31	28	2	2
female	50	9.03	3	high	36.2	30	3	2
female	53	9.27	0	low	25.76	28	2	2
male	56	4.69	0	low	27.62	28	1	1
male	56	5.85	0	low	32.41	28	1	1
male	56	6.3	0	low	23.42	24	1	1
male	53	6.24	1	low	30.19	26	1	1
female	56	5.77	0	low	42.56	29	1	1
female	56	6.26	0	low	26.56	25	1	1
female	55	8.46	0	low	34.55	28	2	2
female	56	4.42	0	low	26.64	30	1	1
female	52	8.26	2	high	45.68	28	2	2
female	56	7.29	0	low	37.11	27	2	2
female	56	6.26	4	high	31.41	23	2	2
female	52	8.1	4	high	31.22	26	2	2
female	46	10.1	0	low	38.75	27	2	2
female	52	8.43	0	low	37.11	28	1	1
male	56	5.6	0	low	34.6	29	1	1
male	56	5.22	2	high	24.4	29	1	1
male	56	7.9	1	low	24.26	28	1	1
female	56	6.4	0	low	43.67	28	1	1
female	56	6.63	0	low	20.58	29	2	2
female	56	5.61	0	low	26.7	29	1	1
female	56	5.59	0	low	29.51	28	1	1
female	56	5.24	0	low	23.44	28	1	1
female	56	5.12	2	high	28.4	29	1	1
female	56	6.58	0	low	32.33	27	1	1
female	56	5.43	0	low	28.64	29	1	1
female	56	4.9	0	low	30	29	1	1
female	56	8.26	1	low	23.32	29	1	1
female	56	8.52	0	low	28.8	29	2	2

Appendix 19: (continued)

MFES1	MFES2	MFES3	MFES4	MFES5	MFES6	MFES7	MFES8	MFES9
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	5	1	7	10	10	7	7	7
10	10	10	10	10	10	10	10	10
9	9	7	9	9	9	9	9	8
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
9	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	9	10	10	10	9
10	10	8	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	5	10	10	5	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
9	10	10	10	10	10	10	9	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	9	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	9	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	8	10	10	10	10	9	10
10	10	8	10	10	10	10	10	10
10	10	10	9	9	10	9	9	10
10	10	8	10	10	10	9	10	10
10	7	7	10	10	10	10	8	6
3	5	5	7	10	10	8	10	6
4	5	8	7	8	8	8	8	8
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
7	8	8	8	8	8	6	7	7
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10

Appendix 19: (continued)

MFES10	MFES11	MFES12	MFES13	MFES14	BBS1	BBS2
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
5	1	1	5	1	4	4
10	10	10	10	10	4	4
9	9	9	8	9	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
9	10	10	10	9	4	4
10	5	5	10	5	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
5	7	7	3	3	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	9	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
10	10	10	9	10	4	4
10	8	8	9	8	4	4
10	10	10	10	10	4	4
10	10	10	9	9	4	4
9	10	10	10	10	4	4
5	3	3	6	6	4	4
9	6	6	6	3	4	4
8	5	2	4	3	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4
4	4	4	0	0	4	4
10	10	10	10	10	4	4
10	10	10	10	10	4	4

Appendix 19: (continued)

BBS3	BBS4	BBS5	BBS6	BBS7	BBS8	BBS9
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	3	4
4	4	4	4	4	4	4
4	4	4	3	4	3	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	3	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	4	3
4	4	4	4	4	3	4
4	4	4	4	4	4	4
4	4	4	4	4	3	4
4	4	4	4	4	4	4
4	4	4	4	4	3	4
4	4	4	4	4	4	4
4	4	4	4	4	4	4
4	4	4	4	4	3	3
4	4	4	4	4	4	4
4	4	4	4	4	4	4

Appendix 19: (continued)

BBS10	BBS11	BBS12	BBS13	BBS14	ROMrgthip	ROMlfthip
4	4	4	4	4	130	130
4	4	4	4	3	125	128
4	4	4	0	1	110	115
4	4	4	4	4	120	122
4	4	4	2	1	110	108
4	4	4	4	3	118	130
4	4	4	2	2	120	115
4	4	4	3	2	120	120
4	4	4	4	4	120	122
4	4	4	4	4	120	125
4	4	4	4	4	125	128
4	4	4	2	3	120	115
4	4	4	4	4	118	120
4	4	4	4	4	124	124
4	4	3	4	4	115	120
4	4	4	4	4	130	130
4	4	4	4	4	112	115
4	4	2	0	1	110	112
4	4	4	1	3	115	115
4	4	4	4	4	110	108
4	4	4	4	4	122	124
4	4	4	4	4	108	108
4	4	4	4	4	110	108
4	4	4	4	4	116	115
4	4	4	4	4	110	112
4	4	4	4	4	120	120
4	4	4	4	4	110	112
4	4	4	4	4	120	118
4	4	4	4	4	112	112
4	4	4	4	4	114	116
4	4	4	4	4	120	120
4	4	3	4	4	120	120
4	4	3	1	1	120	120
4	4	4	1	1	124	122
4	4	1	1	2	130	128
4	4	4	4	3	115	122
4	4	2	4	1	115	112
4	4	3	3	2	115	115
4	4	4	4	4	115	120
4	4	4	3	3	120	120
4	4	4	4	4	122	124
4	4	4	4	4	114	118

Appendix 19: (continued)

ROMrgtknee	ROMlftknee	ROMrgtdf	ROMlftdf	ROMrgtmt	ROMlftmt
125	130	12	13	70	60
130	132	11	12	50	55
110	120	12	10	45	50
125	130	12	10	50	50
110	105	8	10	60	60
125	135	13	12	60	55
130	128	10	12	60	55
140	135	10	10	50	50
122	124	10	10	60	55
130	130	11	10	60	55
120	130	10	12	65	70
120	122	13	17	50	45
118	125	12	10	50	50
132	130	12	12	60	55
118	122	8	10	65	60
122	124	10	12	60	60
115	115	11	10	50	50
110	110	10	10	45	50
114	120	8	10	60	55
125	125	11	12	60	60
140	142	12	13	65	60
126	122	6	8	55	50
150	145	10	7	60	65
138	136	12	10	55	60
130	134	11	12	55	55
132	136	8	10	65	60
134	130	14	14	60	60
130	134	9	10	65	65
134	130	9	10	60	65
142	144	8	10	65	65
136	130	9	10	60	55
120	124	12	12	60	65
120	135	11	10	60	60
125	130	8	8	55	60
140	138	14	14	55	50
110	115	12	14	65	60
112	110	8	10	50	60
110	120	12	11	40	40
122	124	11	12	65	65
120	125	12	15	50	50
142	144	8	8	65	65
140	142	18	18	65	70

Appendix 19: (continued)

strrgtknee	strlftknee	strrgtpf	strlftpf	strrgtdf	strlftdf	strrgttoefl
5	5	3.5	4	5	5	5
5	5	5	5	5	5	4
5	5	3.5	3.5	5	5	3.5
5	5	5	5	5	5	5
4	4	3.5	3.5	4	4	3.5
5	5	4	4	5	5	5
5	5	3.5	3.5	5	5	5
5	5	5	5	5	5	4
5	5	5	5	5	5	5
5	5	5	5	5	5	5
4	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	4	4	3.5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	4	5
4	4	3.5	3.5	4	4	3.5
5	5	4	4	5	5	4
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	5	5	5	5	5
5	5	3.5	4	5	5	5
5	5	3.5	3.5	5	5	5
5	4	4	4	4	4	4
5	5	4	4	5	5	4
5	5	5	5	5	5	5
5	5	4	4	4	4	3
4	4	4	4	4	4	4
5	5	3.5	3.5	5	5	4
5	5	5	5	5	5	5
5	5	4	4	4	4	4
5	5	5	5	5	5	5
5	5	4	4	4	4	5

Appendix 19: (continued)

strifttoefl	strrgttoeext	strifttoeext
5	5	5
4	3.5	3.5
3.5	3.5	3.5
5	5	5
3.5	3.5	3.5
5	5	5
5	5	5
4	4	4
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
3.5	3.5	3.5
4	4	4
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
5	5	5
3.5	3.5	3.5
4	4	4
5	5	5
3	4	4
4	4	4
4	4	4
5	5	5
4	4	4
5	5	5
5	5	5

Vita

June Hanks was born in Winston-Salem, North Carolina on February 2, 1962. After completing grade school and high school, she attended Tennesee Temple University, graduating in 1984 with a Bachelor of Science in Secondary Education/Physical Education. In 1985, she entered the University of Alabama in Birmingham, graduating with a Master of Science in Physical Therapy in 1987. She worked as a physical therapist for 2 years in an acute care setting and for 3 years in an outpatient setting. In 1992, she began teaching in the physical therapy program at the University of Tennessee at Chattanooga. She was granted tenure in 1998. She began her pursuit of the Doctorate in Education at the University of Tennessee at Knoxville in 1993. The doctoral degree was received May, 2000.