DEVELOPMENT AND VALIDATION OF A GAIT CLASSIFICATION SYSTEM FOR OLDER ADULTS – BY MOVEMENT CONTROL AND BIOMECHANICAL FACTORS

by

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Purpose: The purpose of this study was to establish reliability and validity of a clinically useful gait classification system for older adults using gait and physical performance measures in 2 different populations. **Methods**: We classified gait patterns using structured clinical observation and expected the gait patterns to be defined by variability of movement (consistent, inconsistent) and postural biomechanical factors (usual, flexed, extended, crouched) observed in walking. Male veterans (n=106) referred to the VA GEM Program (mean age, 76; SD, 7.1; range, 63-97 years) were videotaped for analyses. The inter- and intra-rater reliability was determined. Pair-wise comparisons across various groups were performed to validate the gait classification using gait parameters (gait speed, step length, width and variability), lower extremity range of motion and muscle strength, physical function in ADL (Physical Performance Test, PPT) and gait abnormalities (GARS-M). The validity of the gait classification system was further validated in a different population consisting of 34 community-dwelling older adults (mean age, 84; SD, 5.0; range, 70-91 years). **Results**: Kappas for interrater reliability of the variability and postural components of the gait classification system were 0.59 and 0.75, respectively; for intrarater reliability, 0.82 and 0.72, respectively. Consistent and inconsistent groups were different in gait speed (0.66 and 0.49m/s, respectively; p=0.003), step length (0.46 and 0.38m; p=0.008), step length variability (7.47% and 12.74%; p=0.043), the PPT (15.80 and 11.73; p<0.001) and GARS-M (5.83 and 10.66; p<0.001). Within both consistent and inconsistent groups, three postural pattern groups (usual, flexed, crouched) differed in gait speed, step length, PPT and GARS-M (p<0.05). When validated in a different population, the mean difference of gait speed across groups was greater than the reported meaningful change. **Conclusions**: Gait patterns of older adults, based on biomechanics and movement control, were reliably recognized and validated by mean differences in abnormal characteristics of gait and physical performance measures across patterns. The variability and postures determined by observation of gait by the

therapists can be used to quickly identify and classify older adults with mobility problems in clinical settings, allowing for possible targeted interventions for specific gait deficits.

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PREFACE

For their help in the preparation of this dissertation, I would like to acknowledge the assistance and support provided by the committee members and faculty members. Many thanks to Dr. Jessie VanSwearingen for her guidance throughout the four years of my Ph.D. program. She is a great mentor who provides constructive input and also pays attention to the details of the project. I would like to thank Dr. Subashan Perera who continues to teach me a lot about statistical methods and data management. I would also like to thank Dr. Jennifer Brach who provided great feedback and insights about gait variability. I greatly appreciate Dr. Stephanie Studenski's academic as well as financial support for the past four years. She has provided me great opportunities to work and gain knowledge in the field of Geriatrics. Many thanks to Dr. George Carvell who first suggested I pursue a career in research. Thank you to my dear friends, Sujuta and Jaime. And finally, thanks to my family who have always been supportive for the decisions I made. This dissertation would not have been possible without the strong support from all of you.

1.0 INTRODUCTION

1.1 THE IMPACT OF GAIT CHANGES

Gait changes occur frequently in older adults,[1] and are often associated with falls,[2-5] ADL and mobility disabilities,[6] nursing home placement,[7] and death.[7] Gait characteristics such as gait speed are often used to describe gait changes and outcomes in older adults.[8-11] Gait speed has been identified as a predictor of ADL and mobility disability outcomes in community-dwelling older adults[12] and decreased gait speed is associated with increased age,[13 14] gait variability,[15] decreased hip and knee flexion range,[13] increased risk of falls[16] and several medical conditions such as arthritis, diabetes mellitus, stroke, and peripheral vascular disease.[13] Self-perceived physical function, as measured by the Sickness Impact Profile (SIP) was predicted by self-selected gait speed.[17] Gait speed alone has been reported as a good predictor of ADLs.[12]

1.2 RELATIONSHIP BETWEEN GAIT CHANGES AND RISKS FOR FALLING

Gait changes such as slow walking speed,[4 18] greater stride-to-stride variability,[15 18 19] and longer double-support time.[4 18] have been related to increased risk for falling in older adults. In a prospective study, Kemoun et al.[4] identified an altered walking pattern showing delayed activation of ankle dorsiflexion at the swing phase among older adults with a history of falls.[4] VanSwearingen et al.[10] found mobility measured by the Modified Gait Abnormality Rating Scale (GARS-M) and the Physical Performance Test the most important factors in identifying individuals with recurrent fall risk. Tromp et al. [5] identified impaired mobility measured by timed walks and chair stands as one of the factors most strongly associated with recurrent falls.

Graafmans et al.[3] identified impaired mobility measured by balance, leg strength, and gait as the major risk factor for single and recurrent falls.

1.3 INTERVENTIONS TO IMPROVE MOBILITY IN OLDER ADULTS

The impact of gait changes magnifies the importance of defining effective interventions to address mobility problems of older adults. In reviewing exercise intervention for improving physical function, several investigators have recommended the need for classification of deficits and targeting intervention based on the specific problems.[20 21] Patterns of gait changes among individuals with mobility problems vary markedly.[1 22] However, many older adults received the same intervention regardless of differences in the patterns of gait disorder.[23-27] In several studies, a generalized exercise program including walking, strengthening, flexibility, or balance exercise was used to improve mobility for older people.[23-27] Few studies have explored the effectiveness of interventions individualized for mobility problems.[28-31] Harada et al.[28] examined the effects of an individualized intervention program relative to four stages of control of gait: mobility, stability, controlled mobility, and skill. Protas et al.[29] designed a problem-oriented exercise program that specifically targeted balance and gait deficits identified from the POAM (Problem-Oriented Assessment of Mobility[32]). Shumway-Cook et al.[30] investigated the effect of multidimensional exercises based on a systems model of postural control in which stability is presumed to emerge from a complex interaction of musculoskeletal and neural systems. Shumway-Cook et al.[30] investigated the effect of multidimensional exercises addressing the impairments and functional disabilities identified during the assessment. Although the subjects in the studies described received one-on-one individualized interventions, no process was defined in a systematic manner for matching the intervention to the specific mobility problems of each patient.

1.4 GAIT CLASSIFICATION SYSTEM FOR OLDER ADULTS WITH MOBILITY PROBLEMS

At present, no treatment-based classification system exists to guide physical therapy intervention for specific deficits of gait of older adults with mobility problems. Previous studies have defined classification of gait in adults in good health and those with history of stroke using biomechanical characteristics of walking.[33-37] Waterlain et al.[36] identified 3 gait patterns in 16 older adults using cluster analysis. The gait of individuals in one cluster was characterized by a walking speed similar to the speed of young subjects, but with an exaggerated cadence. The gait of individuals in the other two clusters was characterized by slow walking speed with either short stride length or decreased cadence. Vardaxis et al.[35] identified 5 groups by gait patterns in 19 young men using cluster analysis. The gait of the men in each group was characterized by different patterns of peak muscle power during walking. Mulroy et al.[34] identified 4 gait patterns in 52 adults after a first stroke. De Quervain et al.[33] classified gait pattern by gait speed in the early recovery period after stroke in 18 adults. Clinical observational data has not been previously used to classify gait patterns of community-dwelling adults with mobility problems. The lack of a gait classification system for older adults with mobility problems magnifies the importance of developing a clinically useful classification system, appropriate for identifying specific gait patterns associated with specific disabilities and responsive to specific interventions.

1.5 A TREATMENT-BASED GAIT CLASSIFICATION

We believe older adults with mobility problems will benefit from a treatment-based classification system which matches the physical therapy interventions to the specific problems observed during gait. Based on reported research and clinical experience, we hypothesized a gait classification system based on movement control factors (two patterns of variability) and biomechanical factors (four postural patterns) observed of older adults walking.[8 15 18 22 38 39] The movement control factor associated with the stepping of gait, while the biomechanical factor associated with the posture of the body during gait.

Older adults with movement control problems may benefit from exercise programs aiming to enhance the automatic repeated stepping pattern. A previous pilot study by VanSwearingen found treadmill training decreased the gait variability in 15 older adults.[40] Hausdorff et al. in 2001 found a exercise program consisting of strengthening and balance training reduced the stride time variability by 50%.[24] Older adults with biomechanical problems (postural deviations) may also benefit from exercise programs. Gait characteristics of 12 female subjects with kyphotic posture improved after a 4-week exercise program.[41] Dynamic peak hip extension and ankle plantar flexion of 47 older adults were increased after a 12-week hip flexor stretching program.[25]

In the proposed gait classification system (Figure 1), the movement control component is classified by the consistency of repeated stepping pattern observed during gait. Individuals were classified as consistent or inconsistent based on the rhythmicity of steppings and walking path. Participants who walked with fluctuations in step lengths or step widths, deviated path, or unexpected trunk sway were classified as being inconsistent. Differences in consistency of gait may be distinguishing characteristics of some deviated gait patterns. For example, gait variability has previously been identified as a significant factor associated with an increased fall risk.[15 18 19] The increased variability during walking has been considered a manifestation of impaired motor control, which reflect errors in control of foot placement and/or center-of-mass or a marker of a more general decline in motor control and balance.[18]

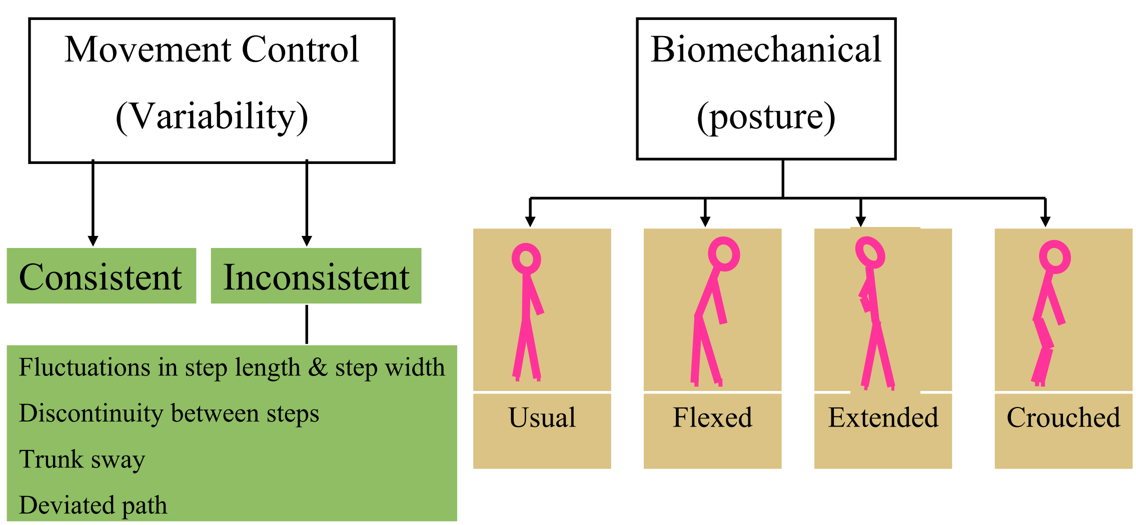


Figure 1: Treatment-Based Gait Classification System

In the proposed observational gait classification, the posture of the body during the gait was classified into one of four categories: usual, flexed, extended, and crouched. The posture is determined by the sagittal alignment of the body during gait. Individuals were classified to the flexed group if the head, shoulder, or trunk were anterior to a vertical line drawn through the hip joint to the ground. Individuals were classified to the extended group if the head, shoulder, or trunk were posterior to a vertical line drawn through the hip joint to the ground. Individuals classified into the crouched group were similar to those of flexed group, but with a flexed knee posture in addition to the head, shoulder and trunk position forward of the vertical. Several studies had examined the relationship between posture and gait.[22 38] Hirose et al.[22] evaluated the effects of four abnormal sagittal postures (thoracic kyphosis, lumbar kyphosis, flat back, and lumbar lordosis) on gait and physical function in 237 older adults. Participants with abnormal posture demonstrated a shorter stride length, longer step width, longer single and double stance time, and slower gait speed. With regard to physical function, those with abnormal posture exhibited slower Timed up & go (TUG) time and a shorter distance on functional reach testing.[22] Balzini et al.[38] found that flexed posture in elderly women is associated with slowing gait and increasing base of support.

1.6 AIMS OF THE STUDY

The purpose of the study was to determine the reliability and validity of an observational gait classification system in community-dwelling older adults with mobility problems. We hypothesize that 1) the patterns of the gait classification system will be reliably recognized, and 2) the gait classification system will be validated by differentiating among those older adults with different levels of walking difficulties and physical functions.

Three phases of analyses were carried out to reliably recognize and validate the gait classification system: (1) We determined the inter and intrarater reliability of the gait classification system, and validated the groups identified using the gait classification system by comparing mean differences in stepping pattern and biomechanical aspects of posture during gait using the individual items of the modified Gait Abnormality Rating Scale (GARS-M) across groups. (2) We further validated the gait classification system determining concurrent validity with gait characteristics and physical function tests, and determined characteristics of gait that define differences among the patterns. (3) We repeated the validation by determining concurrent validity of the gait classification system in a sample from a different population of community-dwelling older adults, using gait characteristics and physical function measures. We expect the hypothesized gait patterns (consistent/usual, inconsistent/usual, consistent/flexed, inconsistent/flexed, consistent/extended, inconsistent/extended, consistent/crouched, and inconsistent/crouched) will be differentially represented in older adults with walking difficulty. Defining a classification system of gait disorders may be useful in the future for targeting interventions for specific deficits of motor control and biomechanical components of gait.

2.0 RELIABILITY AND VALIDITY OF A GAIT CLASSIFICATION SYSTEM FOR OLDER ADULTS WITH MOBILITY PROBLEMS: CLASSIFYING GAIT PATTERNS BY MOVEMENT CONTROL AND BIOMECHANICAL FACTORS

2.1 BACKGROUND AND PURPOSE

Maintaining mobility is important for older adults because mobility has been identified as one of the significant factors associated with falls in community-dwelling older population [3 5 10 42 43]. Performance-based measures of gait[3 5] and observational ratings of abnormalities of gait[10] have been used to demonstrate the importance of mobility in identifying individuals with recurrent fall risk. Among older adults, an increased risk for falling has been related to gait changes such as slow walking speed [4 18], greater stride-to-stride variability [15 18 19], and longer double-support time [4 18]. Mobility has also been demonstrated to be a key factor of disability in activities of daily living (ADLs),[6 12 44] with gait speed alone, nearly as good a predictor of ADL as a battery of gait, balance and lower extremity function measures[12,6]. The relation of gait with falls, mobility and ADL disability in older adults magnifies the importance of developing a classification system appropriate for defining specific gait patterns, which may be useful in targeting interventions for walking problems.

In reviewing exercise intervention for improving physical function, several investigators have recommended the need for classification of deficits and targeting intervention based on the specific problems[20 21]. Patterns of gait changes among individuals with mobility problems vary markedly[1 22]. However, many older adults received the same intervention regardless of differences in the patterns of gait disorder[23-27]. Few studies have explored the effectiveness of interventions individualized for mobility problems[28-31]. Although the subjects in the studies described received one-on-one individualized interventions, no process was defined for matching the intervention to the specific mobility problems of each patient.

At present, no treatment-based classification system exists to guide physical therapy intervention for specific deficits of gait of older adults with mobility problems. Previous studies have defined classification of gait in young and older adults, in good health and those with history of stroke, using kinematic aspects of walking, such as gait speed, cadence, and stride length, or peak muscle power during the gait cycle.[33-37] Clinical observational data has not been previously used to classify gait patterns of community-dwelling adults with mobility problems.

The purpose of the study was to identify gait patterns by observation in older adults with mobility problems, and to determine characteristics of gait that define differences among the patterns. Based on reported research and clinical experience, we hypothesized a gait classification system based on movement control factors (two patterns of variability) and biomechanical factors (four postural patterns) observed of older adults walking[8 15 18 22 38 39]. We determined the inter and intrarater reliability of the gait classification system, and validity of the combinations of variability and posture in gait patterns: consistent/usual, inconsistent/usual, consistent/flexed, inconsistent/flexed, consistent/extended, inconsistent/extended, consistent/crouched, and inconsistent/crouched. We expect the hypothesized gait patterns will be differentially represented in older adults with walking difficulty. Defining a classification system of gait disorders may be useful in the future for targeting interventions for specific deficits of motor control and biomechanical components of gait.

2.2 METHODS

The study was designed to evaluate the reliability and validity of a newly developed observational gait classification system (Appendix A). Videotapes of gait of older adults previously collected to determine gait abnormalities were used. To evaluate reliability of the hypothesized observational gait classification, videotapes of a subset of the sample were evaluated by 2 physical therapists. From the review of the videotapes, each subject was classified into one of the gait pattern described in observational gait classification system (Figure 1).

To evaluate validity, all videotapes of the older adults were reviewed and all subjects were classified using the new gait classification system, and using the established observational rating scale, the modified Gait Abnormality Rating Scale (GARS-M). One of the therapists who classified the subset of subjects for reliability, classified all subjects into one of the gait patterns of the gait classification system. An additional physical therapist, highly experienced in the use of the GARS-M, and blinded to the gait classification system gait pattern determinations, scored the GARS-M for all subjects. The Institutional Review Board of the University of Pittsburgh approved the use of the videotapes to validate the treatment-based gait classification.

2.3 METHODS: SUBJECTS

Community-dwelling veterans referred to the Geriatric Evaluation and Management (GEM) Program of the Veterans Administration Medical Center (Pittsburgh, PA) from May 1993 through September 1995 for mobility problems were videotaped for evaluation. The target population for the GEM Program was community-dwelling older veterans who were experiencing difficulty managing daily activities, including mobility, needed for community dwelling. Nonambulatory older veterans and those with severe dementia or acute terminal illness were generally not seen by the GEM Program team. The inclusion criteria for the study was ambulatory older veterans who used a cane or no assistive device for walking. The videotapes from the first visit to the clinic of each subject was used (n=108). The sample of veterans studied was overwhelmingly male, thus 2 female veterans were excluded to achieve a homogeneous sample. Therefore, the sample for the study included 106 male veterans (mean age, 76; SD, 7.1; range, 63-97 years) (Table 2-1). The first approximately 1/3 of the sample were used for reliability (n=34).

Table 2-1: Number of subjects and mean age in each gait pattern

Gait Pattern	Number of subjects	Mean Age
Usual/consistent	7	71
Flexed/consistent	41	76
Extended/consistent	5	74
Crouched/consistent	6	81
Usual/inconsistent	5	72
Flexed/inconsistent	33	77
Extended/inconsistent	2	77
Crouched/inconsistent	7	81

2.4 METHODS: MEASUREMENTS

2.4.1 Modified Gait Abnormality Rating Scale (GARS-M)

The modified Gait Abnormality Rating Scale (GARS-M) was used to validate the proposed gait classification model. The GARS-M consisted of 7 items and was derived from the original GARS[11] by VanSwearingen et al. in 1996.[45] Construct validity of the GARS-M in the assessment of the recurrent fall risk was defined by the ability of the GARS-M score to distinguish between community-dwelling, frail older persons with a history of falls and frail older persons without a history of falls.[45] Sensitivity (62.3%) and specificity (87.1%) for risk of recurrent falls has been determined, with a cutoff score of 9 for identifying individuals who are at risk for recurrent falls.[10] Concurrent validity of the GARS-M was demonstrated by comparison with quantitative measures of gait speed and stride length. The GARS-M has demonstrated interrater reliability (Kappa coefficient [κ]=.97) and intrarater reliability (κ =.97).[45]

2.4.2 Gait classification system (Figure 1)

The hypothesized observational gait classification system consisted of two components: consistency and posture, representing the components of movement control and biomechanical alignment. Each subject was assigned to one of the two consistency gait patterns, and one of the four posture patterns.

2.5 METHODS: PROCEDURE

2.5.1 Reliability

Videotapes of 34 subjects were initially evaluted to determine the inter and intrarater reliability of the gait classification. The anterior, posterior and lateral veiws were rated to identify the gait patterns by two experienced physical therapist, with one rater repeating the ratings about 3 months later.

2.5.2 Validity

One of the physical therapists who had scored the original 34 subjects later reviewed the videotapes of an additional 72 subjects to identify the gait patterns using the gait classification system. An additional therapist, experienced with the Modified Gait Abnormality Rating Scale (GARS-M) of gait characteristics associated with falling, reviewed the tapes of the 106 subjects and scored the 7 items of the GARS-M for each subject.

2.6 METHODS: DATA ANALYSIS

2.6.1 Reliability

Kappa's Cohen was used to describe interrater and intrarater reliability of the gait classification system, by determining agreement for two components, 1) consistency (consistent, inconsistent), and 2) pattern of posture (usual, flexed, extended, crouched). Ratings using the gait classification system were recorded by two therapists independently at different times and places (interrater reliability). Repeat ratings by one therapist were recorded 3 months later (intrarater reliability).

2.6.2 Validity

Univariate analysis was performed to validate the gait classification by comparing the distribution of the mean scores of the 7 GARS-M items across the gait patterns. A Mann-Whitney test (2-sided p value) was performed to validate the gait patterns by comparing the distribution of the mean scores of the 7 GARS-M items across the 2 gait consistency patterns and 4 postural groups. Kruskal-Wallis test was also used to describe gait patterns by mean rank of GARS-M item scores across pattern.

2.7 RESULTS

2.7.1 Reliability

Interrater reliability for the two raters for the components of gait patterns; consistency and posture, was Kappa statistic for agreement 0.585 and, 0.749 respectively. Intrarater reliability for one rater for a repeat rating of the 2 components; consistency and posture, 3 months later was Kappa statistic for agreement 0.821 and, 0.719 respectively.

2.7.2 Validity: Gait Pattern Component: Consistency

Based on comparison of mean ranks across the patterns, consistent and inconsistent groups were significantly different ($p<.05$) in all GARS-M items and total GARS-M score. Older adults with consistent gait pattern ranked significantly lower in the GARS-M items related to the temporal aspects of gait, such as "variability", "arm-heelstrike synchrony" and "staggering". The mean (SD) for GARS-M total score was 5.83(4.9) for the consistent group and 10.66(4.97) for the inconsistent group (Table 2-2).

Table 2-2: Consistent vs. Inconsistent Group: Medians & Between-Group Mann-Whitney tests of GARS-M items

	Medians		Between Group Comparisons (Mann-Whitney Test)
GARS-M items	Consistent	Inconsistent	Consistent vs. Inconsistent
Variability	1	2	.000*
Guardedness	1	2	.000*
Staggering	0	0	.047*
Foot Contact	1	3	.000*
Hip ROM	0	2	.001*
Shoulder Extension	1	2	.046*
Arm Heelstrike Synchrony	0	2	.001*
GARS-M total score	5	12	.000*

Significant differences between groups ($p<.05$)*

2.7.3 Validity: Gait Pattern Component: Postural patterns within the consistent group

Among the four postural patterns within the consistent group, Kruskal-Wallis test was significant in total GARS-M score and all GARS-M items except for "Staggering". Within the consistent group, 3 distinct postural patterns were identified of the 4 hypothesized postural patterns by comparing the mean ranks in GARS-M items across patterns. All four postural groups, except the flexed compared to extended pattern, differed in GARS-M item scores (Table 2-3). Older adults with usual and flexed postural patterns were different in all GARS-M items except for "staggering". "Guardedness" and "hip ROM" were the most distinguishing factors between the older adults with usual and crouched postures. Hip ROM was the most distinguishing factor between the members of the flexed and crouched groups, and between the members of the extended and crouched groups. Total GARS-M score and the variability and ankle-heel strike synchrony items were different between the members of the usual and extended group. However, no differences were found between the members of the flexed and extended groups.

Table 2-3: Postures within Consistent Group: Medians & Pair-wise Between-Group Mann-Whitney tests of GARS-M items

	Medians				Between-Group Mann-Whitney tests					
GARS-M items	U	F	E	C	U vs. F	U vs. E	U vs. C	F vs. E	F vs. C	E vs. C
Variability	0	1	1	1	.016*	.006*	.004*	.551	.149	.338
Guardedness	0	1	1	2	.023*	.097	.001*	.822	.003*	.012*
Staggering	0	0	0	0	.679	1.000	1.000	.727	.702	1.000
Foot Contact	0	1	0	2	.042*	.915	.002*	.095	.055	.010*
Hip ROM	0	0	0	3	.050*	.237	.001*	.498	.000*	.004*
Shoulder Extension	0	1	1	2	.004*	.170	.004*	1.000	.119	.448
Arm Heelstrike Synchrony	0	0	2	2.5	.021*	.025*	.004*	.230	.012*	.558
GARS-M total score	0	5	4	13	.001*	.023*	.002*	.709	.002*	.021*

Significant differences between groups ($p<.05$)*

U, Usual posture; F, Flexed posture; E, Extended posture; C, Crouched posture.

2.7.4 Validity: Gait Pattern Component: Postural patterns within the inconsistent group

Among the four postural patterns within the inconsistent group, Kruskal-Wallis test was significant in "Foot contact", "Hip ROM" and total GARS-M score. Within the inconsistent group, 3 distinct postural patterns of 4 hypothesized postural patterns were identified by comparing the mean ranks in GARS-M items across patterns. Four postural groups were significantly different from each other except for the usual and the extended pattern (Table 2-4). Older adults with usual and flexed postural patterns were different in "hip ROM" and total

GARS-m score. Hip ROM was the most distinguishing factor between the members of the usual and crouched group, and between the members of the flexed and crouched group. "Foot contact" and "hip ROM" items and total GARS-m score were different between the members of the extended and crouched group. No differences were found between the members of the usual and extended group. "Foot contact" was the only distinguishing factor between the members of the flexed and extended group.

Table 2-4: Postures within Inconsistent Group: Medians & Between-Group Mann-Whitney tests of GARS-M items

	Medians				Between-Group Mann-Whitney tests					
GARS-M items	U	F	E	C	U vs. F	U vs. E	U vs. C	F vs. E	F vs. C	E vs. C
Variability	1	2	1.5	2	.165	.462	.029*	.733	.551	.312
Guardedness	1	2	2	2	.062	.232	.050*	.753	.145	.419
Staggering	0	0	0.5	0	.517	.462	.237	.108	.413	.061
Foot Contact	1	3	0	3	.215	.195	.122	.019*	.293	.023*
Hip ROM	0	2	0.5	3	.002*	.114	.002*	.159	.003*	.024*
Shoulder Extension	0	2	1.5	2	.117	.310	.064	.631	.458	.355
Arm Heelstrike Synchrony	0	2	1	2	.058	.629	.042*	.298	.465	.161
GARS-M total score	4	12	7	14	.032*	.241	.045*	.239	.186	.034*

Significant differences between groups (p<.05)*

U, Usual posture; F, Flexed posture; E, Extended posture; C, Crouched posture.

2.8 DISCUSSION

Despite the variability of gait patterns of older adults with mobility problems, to our knowledge, no studies have used clinical observational data to classify gait patterns in this population. In the study, we classified gait patterns of older adults with mobility problems using structured clinical observation and compared the classification to an established gait assessment tool, based on specific characteristics of gait.[11 45] Differences in gait characteristics among the gait patterns identified by observation were determined. We expected the gait patterns to be defined by variability of movement (consistent, inconsistent) and postural biomechanical factors (usual, flexed, extended, crouched) observed of older adults walking.

2.8.1 Movement control component of gait classification

Older adults were classified to consistent or inconsistent group based on the variability of movement during walking. The most differentiating GARS-M items between consistent and inconsistent gait were "variability", "foot contact", and "guardedness".

Individuals with higher score in "variability" presented greater arrhythmicity of stepping and limb movement. The increased variability during walking may be a manifestation of impaired motor control, reflected in errors in control of foot placement and/or center-of-mass.[18] Increased variability may also be a marker of a more general decline in motor control and balance.[18] Previous studies had identified variability as a significant factor associated with increased fall risk.[15 18 19]

Full score of "foot contact" was scored when the anterior aspect of foot strikes ground before heel. The greater the "foot contact" score, the lesser the degree to which heel strikes the ground before the forefoot. Individuals with inconsistent gait may not strike the heel on the ground during initial contact due to insufficient integration of multimodal sensory inputs and central commands. Lacking momentum in gait, foot placement may be under greater voluntary control. Thus placing the foot could be uneven, given the voluntary guidance substituting for the usual more automatic stepping mechanism and momentum, restrained only by the limits of leg length and joint ROM.

The higher "guardedness" score suggests greater hesitancy, slowness, diminished propulsion and lack of commitment in stepping and arm swing. In the presence of increased variability, center of gravity of head, arms, and trunk (HAT) may shift forwards or backwards with greater tentativity in stepping. Older adults perceiving the variability or alteration of steps and translation may attempt to 'restrict' movement acceleration to reduce increasing variability. Changes in the position of HAT may be strategies to maintain the balance during walking. However, we have no information about the sequence of changes in gait to indicate variability of gait preceded. Guardedness, hesitancy, and slowness of gait could have equally well have been the initial changes in gait, with variability following as a consequence. For example, an older adult concerned (fearful) about falling, may voluntarily reduce the speed of walking and restrict forward momentum. The reduced speed and limited momentum could contribute to hesitancy in the transition from stance to swing, and placing the feet for stepping. Such changes in propulsion could result in increased variability of walking as steps become individually generated, disrupting the acceleration and timing characteristics of the inherent locomotor pattern for stepping.

2.8.2 Biomechanical component of gait classification

Older adults were classified to one of the four postural groups based on the biomechanical alignment observed during walking. An analogy has been drawn between human walking and an inverted pendulum.[46] Dickinson et al. describes locomotion as an inverted pendulum movement as the center of mass vaults over a rigid leg.[46] Kinetic energy in the first half of the stance phase is transformed into gravitational potential energy in the second half of the stance phase.[46] When posture changes, the inverted pendulum movement could be disrupted and result in gait abnormalities. Posture of the trunk is associated not only with the distance and time parameter of gait, but also with functional performance in the elderly.[22] Severe flexed posture of elderly women has been previously associated with slowing gait and increasing the base of support.[38]

Within the consistent and inconsistent group, hip ROM was one of the most differentiating GARS-M items between older adults with usual and flexed gait and flexed and crouched group. Reduction in hip extension may produce shorted contralateral step length and result in slower gait speed.[47] Alternatively, reduced step length may be the initial cause, as a compensation for poor balance.[48] Regardless, reduced hip extension will likely propagate a walking disability followed by insufficient momentum of propulsion. Kerrigan et al.[48] identified peak hip extension during walking as the leg joint parameter that differentiates elderly fallers from the nonfallers. Future research to investigate the differences in gait parameters between older adults with different postures is warranted.

Within both consistent and inconsistent group, guardedness and total GARS-M score were two differentiating factors between the usual and crouched group. Higher score in guardedness suggested the anterior placement of center of gravity of head, arms, and trunk. Older adults with crouched posture tended to lose overall shoulder extension and hip extension during push off due to the forward bended trunk. Total GARS-M score was found to be negatively correlated with walking speed and stride length.[45] The GARS-M score was also related to risk of recurrent falls.[45] Because of the differences in total GARS-M score, older adults with crouched posture are expected to have shorter stride length, slower walking speed, and likely greater risk of recurrent falls.

Among the four postural patterns, we were unable to validate the extended posture. Within the consistent group, the extended posture (n=5) was not different from the flexed posture. Within the inconsistent group, the extended posture (n=2) was not different from the usual group within the inconsistent group. The extended postural group may need to be further validated with more subjects.

2.8.3 Future direction

Although gait patterns of older adults with mobility problems differ, interventions for improving walking vary little.[23-27] We expect the hypothesized observational gait classification will be useful in targeting interventions for specific deficits of movement control and biomechanical components of gait. Intervention such as treadmill training which facilitates regular stepping pattern may be a viable option to reduce gait variability in older adults with movement control problems. Practice of stepping components may be used to restore the rhythmic pattern and propulsion of locomotion. Postural changes accompanied with impairments in the musculoskeletal system can be treated with interventions targeting for the specific biomechanical deviations. Stretching hip flexors may reduce the amount of anterior pelvic tilt, increase the step length, and enhance the more erect trunk posture. Strengthening exercise for lower extremity muscles may be effective in helping older adults negotiate environmental gait challenges.[49]

Future studies using other gait parameters and functional performance measures to validate the classification system is needed. The GARS-M items were the only variables used to validate the classification. By understanding gait parameters such as gait speed and physical performance measures associated with specific gait patterns, patterns identified by the gait classification system could provide information about likely physical function problems and future risks of older adults (e.g. older adults with crouched gait pattern are mostly likely to walk slow and have a higher risk of falling).

3.0 VALIDATION OF A GAIT CLASSIFICATION SYSTEM FOR OLDER ADULTS WITH MOBILITY PROBLEMS USING GAIT CHARACTERISTICS, PHYSICAL PERFORMANCE TEST, AND FALL HISTORY

3.1 BACKGROUND AND PURPOSE

Older adults with gait problems are believed to have a higher risk of falling.[50] Among older adults, an increased risk for falling has been related to gait changes such as slow walking speed,[4 18] greater stride-to-stride variability,[15 18 19] and longer double-support time.[4 18] Mobility has also been related to disability in activities of daily living (ADLs).[6 12 44] Gait speed alone has been reported as a good predictor of ADLs.[12] Poorer performance in tests of lower extremity function, including standing balance, timed walk test, and chair stands, was associated with an increase in subsequent frequency of disability in ADLs.[6] Slowness in rapid gait test (walk back and forth over a 3-m course as quickly as possible) was associated with greater rate of disability in bathing, dressing, walking, and transferring.[44]

Because of the impact of alterations in gait on risks of falling, physical function and ADL, it is important to describe the characteristics of older adults with mobility problems and determine the different patterns of gait alteration. Although the patterns of gait alteration among older adults vary, no classification system is available to differentiate between patterns.[1] Previous studies have defined classification of gait in adults in good health and those with history of stroke,[33-37] but not in community-dwelling older adults with mobility problems. The classification of patterns of gait alteration and targeting interventions based on specific problems within each pattern could enhance the efficacy and efficiency of management of mobility problems in older adults.

Based on reported research and clinical experience, we hypothesized a gait classification system based on movement control factors (two patterns of variability) and biomechanical factors (four postural patterns) observed of older adults walking.[8 15 18 22 38 39] The movement control component is used to describe the variability of stepping while the biomechanical component is used to describe the postural alignment of the body during gait. In a previous investigation, Kappas for interrater reliability of the variability and postural components of the gait classification system were 0.59 and 0.75, respectively; for intrarater reliability, 0.82 and 0.72, respectively. In the prior study, the Modified Gait Abnormality Rating Scale (GARS-M) items were used to compare and contrast gait characteristics across patterns. Gait patterns defined by the variability factor of gait classification (consistent vs. inconsistent) are significantly different from each other in the GARS-M items related to the temporal aspects of gait, such as "variability", "arm-heel strike synchrony" and "staggering". Gait patterns defined by the biomechanical (postural) factor are significantly different across patterns in the GARS-M items related to the biomechanical aspects of gait such as "hip ROM and "guardedness".[51]

For the present study, the purpose was to validate the gait classification system with other gait parameters and physical function tests, and to determine characteristics of gait that define differences among the patterns. We hypothesize that 1) older adults with walking difficulty will exhibit various gait patterns, 2) gait classification system will differentiate among those older adults with different levels of walking difficulties and physical functions.

3.2 METHODS

The study was designed to further evaluate the validity of a newly developed observational gait classification system. Videotapes of 106 older adults were used to determine gait abnormalities. Based on observational analysis of gait from the videotapes, gait of each subject was reviewed and classified into one gait pattern described in the observational gait classification system (Appendix A). Statistical analysis was performed to validate the gait classification by comparing the distribution of the mean values of gait characteristics (gait speed, step length/width, variability), lower extremity range of motion/strength, Physical Performance Test score, and fall history across the gait patterns. Items of the GARS-M were used as input variables in cluster analysis to explore the role of GARS-M in identifying specific gait patterns of older adults. The

Institutional Review Board of the University of Pittsburgh approved the use of the videotapes to validate the treatment-based gait classification.

3.3 METHODS: SUBJECTS

Community-dwelling male veterans (n=106; mean age, 76; SD, 7.1; range, 63-97 years) referred to the Geriatric Evaluation and Management (GEM) Program of the Veterans Administration Medical Center (Pittsburgh, PA) from May 1993 through September 1995 for mobility problems were videotaped for evaluation. The target population for the GEM Program was community-dwelling older veterans who were experiencing difficulty managing daily activities, including mobility, needed for community dwelling. Nonambulatory older veterans and those with severe dementia or acute terminal illness were generally not seen by the GEM Program team. The inclusion criteria for the study was ambulatory older veterans who used a cane or no assistive device for walking. Videotapes of the 2 female veterans were excluded because the remaining sample was overwhelmingly male.

3.4 METHODS: MEASUREMENTS (TABLE 3-1)

3.4.1 Gait Classification System (Figure 1)

The observational gait classification system consisted of two components: variability and posture, representing the components of movement control and biomechanical alignment. Subjects were assigned to one of the two variability gait patterns and one of the four postural patterns.

The movement control component is classified by the consistency of repeated stepping pattern observed during gait. Individuals were classified as consistent or inconsistent based on the rhythmicity of stepping and walking path. Participants walk with fluctuations in step lengths or step widths, deviated path, or unexpected trunk sway are classified as inconsistent.

The posture of the body during gait was classified into one of four categories: usual, flexed, extended, and crouched. The posture is determined by the sagittal alignment of the body during gait. Individuals were classified to the flexed group if the head, shoulder, or trunk were anterior to a vertical line drawn through the hip joint to the ground. Individuals were classified to the extended group if the head, shoulder, or trunk were posterior to a vertical line drawn through the hip joint to the ground. Individuals classified into the crouched group were similar to those of flexed group, but with a flexed knee posture in addition to the head, shoulder and trunk position forward of the vertical.

Table 3-1: Variables used to validate the gait classification system

	Variables
Gait Characteristics	Gait speed (m/s) R and L step length (m) R and L step-length variability (%) Step width (m) Step-width variability (%)
Range of Motion (ROM)	R and L dorsiflexion (degrees) R and L plantar flexion (degrees)
Strength	Grip strength (ft-lbs) R and L dorsiflexor muscle strength (MMT, 1-5) R and L plantar flexor muscle strength (MMT, 1-5)
Physical Performance Test (PPT)	Total score of 7-item PPT (0-28)
History of falls	Fell more than twice in the past year

Variability = coefficient of variation in percent (%); R, right; L, left; MMT, Manual Muscle Test (Kendall, 1993)

3.4.2 Gait characteristics

Gait characteristics including gait speed, step length and width, and variability of step length and width were used to compare means across gait patterns identified by gait classification. Gait characteristics were recorded as described by Wolfson et al[11] and Cerny.[52] Participants wore permanent markers taped to the back of the heel of the shoe, with the tip of the marker just touching the floor, during a timed walk on a 6-m brown-paper walkway.[45 52] Gait speed and step length were determined from the measures of three central strides of the walk to avoid any acceleration or deceleration effects of initiating or stopping a walk.[45] Step width was determined as the distance between the mid sagittal lines of two footprints. The coefficient of variation (COV), (SD/mean) x 100 %, was used to quantify the variability of step length and step width.

3.4.3 Ankle AROM

Bilateral ankle AROM was measured using a biplane goniometer. The value recorded and used in all analyses was the total ankle AROM, defined as the average of the sum of the AROM for plantar flexion and dorsiflexion in both lower extremities. Ankle AROM was measured because of the relationship of ankle AROM to mobility and to the maintenance of the upright posture and because of the potential for decreases in ankle AROM to place older people at risk for a fall.[53-55]

3.4.4 Strength

The muscle strength was determined by MMT graded from 0 to 5: 5, normal amount of resistance to applied force; 4, lesser amount of resistance than 5 but greater than 3; 3, ability to move the segment through its range of motion against gravity; 2, ability to move the segment through its range of motion with decreased gravity; 1, presence of a contraction in the muscle without joint motion; 0, no muscle contraction.[56 57] Each grade was further divided by adding "+" or "–" (eg, 4+, 4-). Maximum voluntary grip strength was measured using a handheld a dynamometer (Jamar grip dynamometer[†]). The grip force was used because of the relation to muscle force production of other muscle groups such as elbow flexors, knee extensors, trunk extensors, and trunk flexors in older adults.[53 58 59] Grip force measured in midlife has also been shown to predict walking disability and self-care disability 25 years later.[53 60]

[†] Sammons Preston, 4 Sammons Ct, Bolingbrook, IL 60440

3.4.5 Physical Performance Test

Physical function was measured using the 7-item Physical Performance Test (PPT), a performance-based measure of physical performance of daily activities, including both BADL and IADL.[61] The PPT was designed for and tested in community-dwelling older adults. The total score obtained for the PPT can be compared with percentile rankings defined for community-dwelling older adults.[62] Higher scores indicate better function. Scores on the PPT were independent predictors of mortality and death or nursing home placement.[62] The PPT scores were also significantly associated with measures of balance, gait speed, shoulder range of motion, grip strength, lower extremity strength, and foot sensation.[63]

3.4.6 History of falls

Subjects were asked if they had 2 or more falls in the past year. In a previous study, older adults with history of recurrent falls experienced significant declines in gait speed, ADL, IADL and the Tinetti Balance and Gait Evaluation score.[64] Two or more falls in the past year represents a substantially greater odds ratio of the older person falling than for the older person who fell once or not at all in the previous year.[65 66]

3.5 METHODS: DATA ANALYSIS

In order to validate the gait classification system, multiple comparison tests were used to describe the differences in gait parameters and physical function between the patterns. Cluster analysis was carried out to explore the role for cluster analysis in identifying older adults with different gait patterns.

3.5.1 Multiple comparison tests

Multiple comparison tests were performed to validate the gait classification. Gait parameters and physical function measures of the older adults were used to describe the differences between the patterns identified by the hypothesized gait classification. The comparisons were made between the consistent and inconsistent groups and between four postural groups within consistent and inconsistent groups. The variables used in the study to validate the gait classification system are listed in Table 3-1. T-test and Mann-Whitney test were used for pair-wise comparisons. An ANOVA and Kruskal-Wallis test were used to determine overall significant differences across the groups defined by gait patterns. Fisher's LSD was used as a post-hoc test when ANOVA was significant. Chi-square test was used to determine if the proportion of those who had more than 2 falls in the past year was significantly greater among those without consistent gait and usual posture.

3.5.2 Cluster Analysis

Gait patterns identified by the hypothesized gait classification were compared with clusters generated by cluster analysis using GARS-M items as input variables. The SPSS TwoStep Cluster Analysis (SPSS, Inc., Chicago, IL) was chosen as the clustering technique to classify the gait patterns of older adults. The SPSS TwoStep Cluster Component handles both continuous and categorical variables and provides the options to fix the number of cluster solutions or automatically determine the optimal number of clusters.[67] The selection of distance measure determines how the similarity between two clusters is computed. Because the dataset consists of a combination of continuous and categorical variables, the Log-likelihood distance measure is used.[68] The likelihood measure places a probability distribution on the variables. The method assumes that variables in the cluster model are independent and all continuous variables are normally distributed while categorical variables are multinomial. The procedure was fairly robust to the violations of the assumptions.[68]

In the first step, a sequential clustering approach was used to scan the records one by one and decides if the current record should merge with the previously formed clusters or start a new cluster based on the distance criterion. Many small sub-clusters were generated in the first step of the procedure. In the second step, the sub-clusters resulting from the first step were used as inputs and grouped into the desired number of clusters. The SPSS program uses the agglomerative hierarchical clustering method primarily in the second step. Since the clustering solutions may depend on the order of cases, cases were sorted in different random orders to minimize the ordering effect and verify the stability of a given solution.

3.5.3 Agreement

Kappa coefficients were used to compare the patterns identified by cluster analysis and the hypothesized visual gait classification. Positive and negative agreements are also used as indices of agreement between the cluster analysis results and the visual gait classification. The agreement indices were developed to address the situation of a high inter-observer agreement, but low Kappa value.[69 70] The value of positive agreement quantifies the probability that, for a typical subject given a positive rating by a typical observer, another observer will agree (i.e., that a second opinion will also be positive). The value of negative agreement defines a similar quantity for a typical negative rating.

3.6 RESULTS

3.6.1 Multiple Comparison Tests

3.6.1.1 Consistent vs. inconsistent group

The results of multiple comparison tests are shown in Table 3-2. Subjects with consistent and inconsistent gait differed in walking speed, right step length, right step length variability, left dorsi-flexion ROM, right plantar flexion ROM, left dorsi-flexor muscle strength, and Physical Performance Test score ($p<.05$). Only right step length is reported because there were no statistical differences between right and left step length (right step length mean=0.42, SD, 0.15; left step length mean=0.41, SD,0.15; T=1.242, p=0.217).

Table 3-2: Mean (SD) and Pair-wise comparisons between consistent and inconsistent gait pattern

Variables	Consistent Group (n=59)	Inconsistent group (n=47)	Mean difference
Gait speed (m/s)	0.66 (0.29)	0.49 (0.24)	0.17*
R step length (m)	0.46 (0.15)	0.38 (0.14)	0.08*
R step length S.D.	0.03 (0.02)	0.04 (0.03)	-0.01
Rstep length variability (coefficient of variation, %)	7.47 (6.27)	12.74 (17.06)	-5.27†
Step width (m)	0.11 (0.05)	0.11(0.05)	0.003
Step width S.D.	0.03 (0.02)	0.03 (0.02)	-0.004
Step width variability (coefficient of variation, %)	29.17 (45.01)	35.78 (65.4)	-6.62
Grip strength (ft-lbs)	49.67 (26.26)	48.10 (17.41)	1.57
Physical Performance Test (0-28)	15.80 (5.29)	11.73 (4.86)	4.08†
2 or more falls in past year (%)	50	70	P=0.11
R dorsiflexion (degrees)	11.04 (6.35)	10.39 (6.81)	0.65
L dorsiflexion (degrees)	10.30 (7.20)	6.90 (7.70)	3.39*
R plantar flexion (degrees)	30.20 (6.05)	27.12 (6.97)	3.09*
L plantar flexion (degrees)	29.60 (6.15)	26.48 (8.95)	3.13
R dorsiflexor muscle strength (MMT,1-5)	4.45 (0.60)	4.39 (0.62)	0.06
L dorsiflexor muscle strength (MMT,1-5)	4.44 (0.63)	4.19 (0.51)	0.24†
R plantar flexor muscle strength (MMT,1-5)	4.67 (0.45)	4.74 (0.43)	-0.07
L plantar flexor muscle strength (MMT,1-5)	4.75 (0.42)	4.70 (0.45)	0.05

* significant in t-test; † significant in Mann-Whitney test

R, right; L, left; MMT, Manual Muscle Test (Kendall, 1993); MMT grades were converted to numerical value: 3+, 3.3; 4-, 3.7; 4+, 4.3

3.6.1.2 Consistent group: usual vs. flexed vs. extended vs. crouched

Among the subjects with consistent gait, four postural groups differed in gait speed, right step length, step width, Physical Performance Test, and the proportions who had 2 or more falls in the past year (ANOVA or Kruskal-Wallis test, p<.05) (Table 3-3). Differences were found between groups except for the flexed and extended group and the extended and crouched group (Table 3-4).

Table 3-3: Results of ANOVA, Kruskal-Wallis test, or Chi-square test and means (SD) for 4 postural patterns within the consistent group

Variables	Usual (n=7)	Flexed (n=41)	Extended (n=5)	Crouched (n=6)
Gait speed (m/s)*	0.94 (0.31)	0.65 (0.29)	0.55 (0.14)	0.48 (0.24)
R step length (m)*	0.59 (0.11)	0.46 (0.14)	0.45 (0.12)	0.29 (0.10)
R step length S.D.	0.03 (0.03)	0.03 (0.02)	0.02 (0.02)	0.04 (0.02)
R step length variability (coefficient of variation, %)	5.03 (4.2)	7.18 (6.01)	6.46 (6.84)	15.1 (7.14)
Step width (m)†	0.08 (0.04)	0.11 (0.05)	0.12 (0.04)	0.17 (0.06)
Step width S.D.	0.04 (0.02)	0.03 (0.02)	0.02 (0.01)	0.02 (0.02)
Step width variability	49.99 (28.76)	29.75 (50.71)	18.92 (14.91)	10.57 (11.96)
Grip strength (ft-lbs)	60.67 (34.67)	50.43 (24.64)	48.20 (32.06)	28.00 (13.64)
Physical Performance Test (0-28)†	21.5 (2.43)	15.38 (5.00)	16.20 (4.76)	9.00 (4.36)
2 or more falls in past year (%)¥	0	58	20	100
R dorsiflexion (degrees)	13.37 (3.09)	10.85 (6.33)	12.94 (7.78)	7.02 (8.36)
L dorsiflexion (degrees)	11.77 (4.32)	10.65 (5.93)	9.22 (14.01)	6.15 (11.74)
R plantar flexion (degrees)	31.51 (6.30)	29.95 (6.17)	32.59 (2.50)	27.58 (8.24)
L plantar flexion (degrees)	31.26 (6.37)	29.59 (5.74)	32.01 (3.66)	24.23 (10.41)
R dorsiflexor muscle strength (MMT,1-5)	4.88 (0.29)	4.48 (0.59)	3.93 (0.73)	4.2 (0.17)
L dorsiflexor muscle strength (MMT,1-5)	4.77 (0.36)	4.44 (0.66)	4.18 (0.61)	4.23 (0.68)
R plantar flexor muscle strength (MMT,1-5)	4.88 (0.29)	4.66 (0.45)	4.4 (0.59)	4.75 (0.50)
L plantar flexor muscle strength (MMT,1-5)	4.83 (0.41)	4.7 (0.44)	4.8 (0.45)	5 (0.00)

* significant in ANOVA

† significant in Kruskal-Wallis test

¥ significant in chi-square test

R, right; L, left; MMT, Manual Muscle Test (Kendall, 1993)

MMT grades were converted to numerical value: 3+, 3.3; 4-, 3.7; 4+, 4.3

Table 3-4: Pair-wise comparisons between 4 postural patterns within the consistent group

	Pair-wise between Group Comparisons (mean difference)					
Variables	U vs. F	U vs. E	U vs. C	F vs. E	F vs. C	E vs. C
Gait speed (m/s)	0.28*	0.39*	0.46*	0.10	0.18	0.07
R step length (m)	0.13*	0.14	0.29*	0.01	0.17*	0.15
R step length S.D.	-0.00	0.01	-0.01	0.01	-0.01	-0.02
R step length variability (coefficient of variation, %)	-2.15	-1.43	-10.06†	0.72	-7.91†	-8.64
Step width (m)	-0.02	-0.03	-0.09*	-0.01	-0.07*	-0.05
Step width S.D.	0.01	0.02	0.02	0.01	0.01	-0.00
Step width variability (coefficient of variation, %)	20.24	31.07	39.42	10.83	19.18	8.35
Grip strength (ft-lbs)	10.23	12.47	32.67	2.23	22.43	20.20
Physical Performance Test (0-28)	6.12†	5.30	12.50†	-0.82	6.38†	7.20
2 or more falls in past year (%)	P=0.098	P=1.000	P=1.000	P=0.169	P=0.508	P=0.143
R dorsiflexion (degrees)	2.52	0.43	6.35	-2.09	3.83	5.92
L dorsiflexion (degrees)	1.12	2.55	5.62	1.43	4.50	3.07
R plantar flexion (degrees)	1.56	-1.08	3.93	-2.64	2.37	5.01
L plantar flexion (degrees)	1.67	-0.74	7.03	-2.41	5.37	7.78
R dorsiflexor muscle strength (MMT,1-5)	0.41	0.96	0.68†	0.55	0.28	-0.27
L dorsiflexor muscle strength (MMT,1-5)	0.33	0.59	0.53	0.26	0.20	-0.05
R plantar flexor muscle strength (MMT,1-5)	0.22	0.48	0.13	0.26	-0.09	-0.35
L plantar flexor muscle strength (MMT,1-5)	0.13	0.03	-0.17	-0.09	-0.29	-0.20

* significant in t-test

† significant in Mann-Whitney test

R, right; L, left; MMT, Manual Muscle Test (Kendall, 1993)

U, Usual; F, Flexed; E, Extended; C, Crouched.

3.6.1.3 Inconsistent group: usual vs. flexed vs. extended vs. crouched

Among the subjects with inconsistent gait, four postural groups differed in gait speed, right step length, and Physical Performance Test (ANOVA or Kruskal-Wallis test, $p<.05$) (Table 3-5). Pair-wise comparisons involving extended group were not performed because there were only 2 cases in the extended group (Table 3-6). Differences were found between the usual and the flexed, the usual and the crouched, and the flexed and the crouched (Table 3-6).

Table 3-5: Results of ANOVA, Kruskal-Wallis test, or Chi-square test and means (SD) for 4 postural patterns within the inconsistent group

Variables	Usual (n=5)	Flexed (n=33)	Extended (n=2)	Crouched (n=7)
Gait speed (m/s)*	0.67 (0.23)	0.50 (0.23)	0.44	0.29 (0.19)
R step length (m)*	0.53 (0.08)	0.38 (0.13)	0.43	0.26 (0.08)
R step length S.D.	0.03 (0.02)	0.04 (0.03)	0.04	0.03 (0.02)
R step length variability (coefficient of variation, %)	6.24 (2.66)	14.04 (19.77)	9.22	12.46 (8.91)
Step width (m)	0.11 (0.05)	0.11 (0.05)	0.11	0.09 (0.07)
Step width S.D.	0.04 (0.02)	0.03 (0.02)	0.06	0.03 (0.02)
Step width variability (coefficient of variation, %)	42.93 (29.24)	41.08 (71.05)	58.09	0.52 (58.89)
Grip strength (ft-lbs)	39.20 (10.83)	49.07 (19.51)	65	48.17 (8.50)
Physical Performance Test (0-28)†	17.60 (3.36)	11.75 (4.16)	10.00	7.00 (4.43)
2 or more falls in past year (%)	33	56	100	100
R dorsiflexion (degrees)	11.40 (5.21)	9.10 (6.17)	21.33	14.02 (9.28)
L dorsiflexion (degrees)	10.74 (1.76)	6.90 (7.13)	12.67	2.78 (12.5)
R plantar flexion (degrees)	28.47 (5.95)	26.99 (7.59)	34.33	25.39 (4.73)
L plantar flexion (degrees)	28.75 (5.88)	25.94 (9.68)	38.67	25.11 (7.10)
R dorsiflexor muscle strength (MMT,1-5)	4.6 (0.59)	4.36 (0.57)	5	4.27 (0.94)
L dorsiflexor muscle strength (MMT,1-5)	4.6 (0.55)	4.12 (0.50)	4	4.25 (0.56)
R plantar flexor muscle strength (MMT,1-5)	4.8 (0.45)	4.73 (0.45)	5	4.73 (0.38)
L plantar flexor muscle strength (MMT,1-5)	4.66 (0.48)	4.71 (0.46)	5	4.58 (0.51)

* significant in ANOVA

† significant in Kruskal-Wallis test

R, right; L, left; MMT, Manual Muscle Test (Kendall, 1993)

MMT grades were converted to numerical value: 3+, 3.3; 4-, 3.7; 4+, 4.3

Table 3-6: Pair-wise comparisons between 4 postural patterns within the inconsistent group

	Pair-wise between Group Comparisons (mean difference)		
Variables	U vs. F	U vs. C	F vs. C
Gait speed (m/s)	0.16	0.38*	0.22*
R step length (m)	0.15*	0.27*	0.12*
R step length S.D.	-0.00	0.00	0.01
R step length variability (coefficient of variation, %)	-7.80	-6.21	1.58
Step width (m)	0.00	0.02	0.02
Step width S.D.	0.01	0.01	-0.00
Step width variability (coefficient of variation, %)	1.86	42.42	40.56
Grip strength (ft-lbs)	-9.87	-8.97	0.90
Physical Performance Test (0-28)	5.85†	10.60†	4.75†
2 or more falls in past year (%)	P=0.249	P=0.400	P=1.000
R plantar flexion (degrees)	1.47	3.08	1.61
L plantar flexion (degrees)	2.81	3.64	0.83
R dorsiflexion (degrees)	2.30	-2.62	-4.92
L dorsiflexion (degrees)	3.84	7.96	4.12
R dorsiflexor muscle strength (MMT,1-5)	0.24	0.33	0.09
L dorsiflexor muscle strength (MMT,1-5)	0.48	0.35	-0.13
R plantar flexor muscle strength (MMT,1-5)	0.08	0.07	-0.00
L plantar flexor muscle strength (MMT,1-5)	-0.05	0.09	0.14

* significant in t-test; † significant in Mann-Whitney test

R, right; L, left; MMT, Manual Muscle Test (Kendall, 1993); U, Usual; F, Flexed; E, Extended; C, Crouched.

U vs. E, F vs. E, E vs. C were not in the table (Post-hoc test was not performed; n=2 in extended group).

3.6.2 Cluster Analysis

TwoStep Cluster Analysis automatically generated 2 clusters of subjects when “variability” and “arm-heel strike synchrony” component of GARS-m were used as the input variables. The results of cluster analysis are shown in Table 3-7. Cluster 1 was compared with the consistent group while cluster 2 was compared with the inconsistent group (Table 3-8).

Within both the consistent and inconsistent group, TwoStep Cluster Analysis generated 4 clusters when 7 GARS-M items and total GARS-M score were used as input variables. The number of clustering solutions was fixed to 4 because we believed in the hypothesis of 4 possible postural patterns in older adults. The results of cluster analysis for consistent and inconsistent groups are shown in Table 3-9 and 3-10. Cluster 1, 2, 3, and 4 were compared with the usual, flexed, extended, and crouched posture, respectively (Table 3-11, Table 3-12).

Table 3-7: Results of TwoStep Cluster Analysis: Means (SD) of clusters

	Means (SD) of GARS-M items	
	Variability	Arm-heelstrike synchrony
Cluster 1 (n=50)	1.82 (0.69)	2.42 (0.64)
Cluster 2 (n=56)	0.48 (0.48)	0.29 (0.56)

Note: Cluster 1 was assumed to be comparable with the consistent group due to higher scores of "variability" and "arm-heelstrike synchrony". Cluster 2 was comparable with the inconsistent group. The agreement between the patterns identified by cluster analysis and the hypothesized visual gait classification was examined for each subject. Kappa coefficients and positive and negative agreements were used to compare the patterns identified by cluster analysis and the hypothesized visual gait classification. The Kappa statistic for agreement was 0.411 ($p<.05$) when the subjects were classified based on the variability component of gait classification. The value of positive agreement was 73% for the consistent group and 68% for the inconsistent group.

Table 3-8: Agreement between cluster analysis and gait classification system

	Cluster 1	Cluster 2	Total
Consistent	42	17	59
Inconsistent	14	33	47
Total	56	50	106

Table 3-9: Results of TwoStep Cluster Analysis within the consistent group: Means (SD) of clusters

	Means (SD) of GARS-M items							
	Variability	Guardedness	Staggering	Foot Contact	Hip ROM	Shoulder extension	Arm-heelstrike synchrony	Total score
Cluster 1 (n=11)	0.18 (0.41)	0.00 (0.00)	0.00 (0.00)	0.45 (1.04)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.64 (1.03)
Cluster 2 (n=19)	0.37 (0.50)	0.79 (0.42)	0.00 (0.00)	0.63 (0.68)	0.37 (0.60)	1.37 (0.76)	0.53 (0.77)	4.05 (1.68)
Cluster 3 (n=9)	0.22 (0.44)	0.00 (0.00)	0.11 (0.33)	0.56 (0.73)	0.00 (0.00)	1.00 (0.00)	0.33 (0.71)	2.22 (1.72)
Cluster 4 (n=20)	1.45 (0.69)	2.05 (0.51)	0.00 (0.00)	2.45 (0.83)	1.90 (1.02)	2.05 (0.83)	2.10 (0.91)	12.00 (1.95)

Cluster 1, 2, 3, and 4 were compared with the usual, flexed, extended, and crouched posture, respectively

Table 3-10: Results of TwoStep Cluster Analysis within the inconsistent group: Means (SD) of clusters

	Means (SD) of GARS-M items							
	Variability	Guardedness	Staggering	Foot Contact	Hip ROM	Shoulder extension	Arm-heelstrike synchrony	Total score
Cluster 1 (n=11)	1.00 (0.45)	0.82 (0.60)	0.09 (0.30)	0.91 (1.14)	0.18 (0.41)	0.36 (0.51)	0.18 (0.60)	3.55 (1.70)
Cluster 2 (n=17)	1.47 (0.62)	1.82 (0.39)	0.00 (0.00)	2.24 (1.15)	1.71 (0.85)	1.47 (0.80)	1.59 (0.87)	10.29 (2.71)
Cluster 3 (n=10)	2.10 (0.74)	2.80 (0.63)	0.40 (0.97)	2.90 (0.32)	1.90 (1.20)	2.40 (0.84)	2.90 (0.32)	15.40 (1.90)
Cluster 4 (n=9)	2.33 (0.50)	2.00 (0.00)	0.33 (0.71)	2.33 (0.71)	2.11 (0.78)	3.00 (0.00)	2.67 (0.50)	14.78 (1.56)

Cluster 1, 2, 3, and 4 were compared with the usual, flexed, extended, and crouched posture, respectively.

Table 3-11: Agreement between cluster analysis and gait classification system within consistent group

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
Usual	5	1	1	0	7
Flexed	5	17	7	12	41
Extended	1	1	1	2	5
Crouched	0	0	0	6	6
Total	11	19	9	20	59

Table 3-12: Agreement between cluster analysis and gait classification system within inconsistent group

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
Usua4	4	0	1	0	5
Flexed	6	13	7	7	33
Extended	1	1	0	0	2
Crouched	0	3	2	2	7
Total	11	17	10	9	47

3.6.3 Agreement

The agreement between the clusters identified by cluster analysis and the hypothesized visual gait classification was examined using the Kappa statistic. The Kappa statistic for agreement was 0.411 ($p<.05$) when the subjects were classified based on the variability component of gait classification. The value of positive agreement was 73% for the consistent group and 68% for the inconsistent group. Within the consistent group, Kappa statistic for agreement was 0.280 ($p<.05$) when the subjects were classified based on the postural components. The value of positive agreement was 56% for the usual group, 57% for the flexed group, 14% for the extended group, and 46% for the crouched group. Within the inconsistent group, the Kappa statistic for agreement was 0.128 ($p>.05$) when the subjects were classified based on the postural components. The value of positive agreement was 50% for the usual group, 52% for the flexed group, 0% for the extended group, and 25% for the crouched group.

3.7 DISCUSSION

In order to quickly identify and classify older adults with mobility problems in clinical settings, an observational gait classification was developed and tested. Older adults were first categorized as walking with consistent or inconsistent gait based on the observational ratings of walking patterns by physical therapists from the videotapes. The consistency component was used to define the motor-control part of gait. Following the classifying by variability, the older adults were categorized as walking with usual, flexed, extended, or crouched posture. The postural component was used to define the biomechanical alignment of the body during gait. The variability and postural type determined using the gait classification were validated by multiple comparison tests and compared with patterns generated by cluster analysis.

We were able to validate both the movement control and biomechanical component of the gait classification by comparing differences in gait speed, fall history, gait parameters, GARS-M score and Physical Performance Test across patterns.

3.7.1 Gait speed as a differentiating factor among groups

Gait speed has been identified as a predictor of ADL and mobility disability outcomes in community-dwelling older adults[12] and decreased gait speed is associated with increased age,[13 14] gait variability,[15] decreased hip and knee flexion range,[13] increased risk of falls[16] and several medical conditions such as arthritis, diabetes mellitus, stroke, and peripheral vascular disease.[13] The differences of gait speed between the consistent and inconsistent groups suggested that it's possible for clinicians to use the classification to identify individuals at higher risk of ADL and mobility disability and possibly those with higher gait variability and insufficient lower extremity range of motion. The use of gait speed for distinguishing community-dwelling older people who are at risk or not at risk for recurrent falls has been demonstrated with a sensitivity of

72% and a specificity of 74% and with a cutoff score for recognizing fall risk of 0.56m/s.[10 53] In our study, the consistent and inconsistent group walked at the mean speed of 0.66 m/s and 0.49 m/s, respectively. Based on the relations described, older adults identified as being inconsistent during walking may be presumed to have a higher risk of falling. Within both consistent and inconsistent groups, mean gait speeds of four postural groups were different from each other except for the extended group (Table 4 & 6). The usual group walked the fastest, followed by the flexed, extended, and the crouched (Table 3 & 5). The differences of mean gait speeds across patterns were greater than the substantial meaningful change (0.08 to 0.14 m/s) identified by Perera et al.[71]

3.7.2 Fall history as a differentiating factor among groups

Based on previous studies, older adults who fell twice or more in the previous year were more likely to fall again.[65 66] Although there is no statistical differences, in our study, among those with consistent gait, 50% fell more than twice during the past year while among those with inconsistent gait, 70% fell more than twice during the past year. All older adults with crouched posture fell more than twice during the past year regardless of variability of gait. The gait classification system can potentially be useful to identify older adults at greater risks of falling.

3.7.3 Gait variability as a differentiating factor among groups

Previous studies reported increased gait variability among community-living older adults with a history of falls.[15 19] Maki et al. [18] identified stride-to-stride variability as an independent predictor of falling. Hausdorff et al.[15] found stride time variability correlated significantly with multiple factors such as strength, balance, gait speed, functional status, and mental health. In our study, the inconsistent group walked with significantly shorter step lengths and significantly higher step length variability. Therefore, we suggest that the subjects in the inconsistent group are at greater risks of falling. Within both consistent and inconsistent groups, mean right and left step lengths of four postural groups were different from each other except for the extended group. The usual group walked with the longest step lengths, followed by the flexed, extended, and the crouched. The longer the step length, the faster the gait speed. The differences in the step lengths across postural groups correspond to the differences in gait speeds in this study. No statistical differences in step width variability were found between groups. Brach et al.[72] reported that extreme step width variability is associated with falls in the past year in older adults who walk at or near normal gait speed and not in older persons who walk slower than 1.0 m/s. The mean gait speed of subjects participated the study is 0.59 m/s. The results from our study support the finding.

3.7.4 Physical Performance Test as a differentiating factor among groups

The PPT has been used to describe and monitor physical performance, to screen for falls, and to predict the need for institutionalization and the likelihood of death.[73] Higher PPT scores indicate better performance.[61] In our study, older adults with inconsistent gait had significantly lower PPT score in comparison with those with consistent gait. Among the 4 postural groups, the usual group demonstrated the highest PPT score, followed by the flexed and extended, and the crouched group. Identifying older adults with inconsistent gait and different postures may help clinicians understand the physical functions of older adults.

3.7.5 Role of cluster analysis

Using cluster analysis with GARS-M items as input variables older adults with consistent and inconsistent gait were identified. The Kappa statistic, and positive and negative agreement showed significant agreement between the clustering solutions and the hypothesized visual gait classification. However, using cluster analysis with GARS-M items as input variables, we were unable to identify the postural pattern of older adults. The disagreement occurred mostly in the assignment of individuals with flexed posture. Further analysis removing the flexed group showed a dramatic increase in the agreement indices. In the consistent group, the Kappa statistic increased to .665 and the value of positive agreement increased to 77% for the usual group, 60% for the extended group, and 92% for the crouched group after the removal of the cases with flexed posture. In the inconsistent group, the Kappa statistic increased to .421 and the value of positive agreement increased to 89% for the usual group, 0% for the extended group, and 71% for the crouched group after the removal of the cases with flexed posture.

3.7.6 Future direction

One major limitation of the study was that only the male community-dwelling veterans were included. The sample sizes of 4 postural groups are very different because the majority of older adults walk with a flexed posture. However, the large proportion of older adults with flexed posture does represent the prevalence of flexed posture in this population. In order to apply the gait classification to the community-dwelling older adults, the classification system needs to be further validated with a different sample of population consisting of both genders.

4.0 VALIDATION OF A GAIT CLASSIFICATION SYSTEM FOR OLDER ADULTS WITH MOBILITY PROBLEMS USING GAIT CHARACTERISTICS, SIX-MINUTE WALK TEST, MODIFIED GAIT ABNORMALITY RATING SCALE (GARS-M), AND FUNCTIONAL STATUS QUESTIONNAIRE (FSQ)

4.1 INTRODUCTION

Among older adults, gait changes such as slow walking speed [4 18], greater stride-to-stride variability [15 18 19], and longer double-support time [4 18] have been related to higher risks of falling. Gait speed alone has been reported as a good predictor of ADLs[12] and slow gait has been associated with a greater rate of disability in bathing, dressing, walking, and transferring[44] and in general with ADL disability[6 12 44].

Although various patterns of changes in gait have been described among older adults,[1 74] no classification system is available to differentiate between the patterns of gait changes. Previous studies have defined classification of gait in adults in good health and those with history of stroke[33-37], but not in community-dwelling older adults with mobility problems. In reviewing exercise intervention for improving physical function, several investigators have recommended the need for classification of deficits and targeting intervention based on the specific problems[20 21]. Because of the relations of gait with risks of falling and performance of ADLs and lack of gait classification in older adults, we believe it is important to develop a clinically feasible classification system appropriate for specific gait classifications.

Based on reported research and clinical experience, we hypothesized a gait classification system based on movement control factors (two patterns of variability) and biomechanical factors (four postural patterns) observed of older adults walking[8 15 18 22 38 39]. The movement control component is used to describe the consistency of gait while the biomechanical component is derived from the postural alignment of the body during gait. In a previous study, the gait patterns of the classification system were reliably recognized and validated using modified Gait Abnormality Rating Scale (GARS-M) in community-dwelling older male veterans.[51] Kappas for interrater reliability of the variability and postural components of the gait classification system were 0.59 and 0.75, respectively; for intrarater reliability, 0.82 and 0.72, respectively.[51] Gait patterns defined by the variability factor of the gait classification (consistent vs. inconsistent) are significantly different from each other in the GARS-M items related to the temporal aspects of gait, such as "variability", "arm-heel strike synchrony" and "staggering". Gait patterns defined by the biomechanical (postural) factor are significantly different across patterns in the GARS-M items related to the biomechanical aspects of gait such as "hip ROM and "guardedness".

In a follow-up study with the same population, the concurrent validity of gait classification was evaluated by comparing gait characteristics and physical function tests across patterns.[75] Consistent and inconsistent groups were different in walking speed, Physical Performance Test (PPT) and gait variables such as step length and variability. Four postural groups were different from each other in the PPT and gait speed ($p<.05$).[75]

In order to apply the classification to a more general population of community-dwelling older adults, the validity of the classification needs to be evaluated in a different sample consisting of both genders. The purpose of the study was to validate the gait classification system in a population consisting of both males and females, and to determine characteristics of gait that define differences among the patterns. We hypothesize for the target population for the study, 1) the gait classification system can be used to differentiate among older adults with different patterns of walking difficulties, and 2) gait characteristics and ADLs will differ among older adults classified to different gait patterns.

4.2 METHODS

To evaluate validity, gait patterns of the new classification system were determined from the review and scoring of videotapes of 34 older adults, previously collected to determine gait abnormalities at baseline for subjects enrolled an intervention trial to improve walking. Each subject was classified into one gait pattern described in the observational gait classification system (Appendix A).

Statistical analysis was performed to validate the gait classification by comparing the distribution of the mean values of gait characteristics (gait speed, step length and step width, stance time, and variability), Six-Minute Walk Test, GARS-M, and Functional Status Questionnaire (FSQ) across the gait patterns (Table 4-1). The Institutional Review Board of the University of Pittsburgh approved the use of the videotapes to validate the treatment-based gait classification.

Table 4-1: Variables used to validate the gait classification system

	Variables
Gait Parameters	Gait speed (m/s) Step length (m), step-length variability (%) Step width (m), step width variability (%) Stance time (seconds), stance time variability (%)
6-minute walk test	Distance walked (m)
Modified Gait Abnormality Rating Scale (GARS-M)	Scores of 7 GARS-M items (0-3) Total GARS-M score (0-21)
Functional Status Questionnaire (FSQ)	ADL (0-100) IADL (0-100)

Variability = coefficient of variation (SD/mean *100) in percent (%)

4.3 METHODS: SUBJECTS

Community-dwelling older adults living independently or in assisted living at a senior continuing care residential community in Pittsburgh, who were enrolled in a clinical trial of walking, participated (n = 34; mean age, 84; SD, 5.0; range, 70-91 years). The inclusion criteria for the trial were: (1) age 65 years and older, (2) self-reported decline in walking ability, or walking speed $\leq$ 1.0m/s, (3) independent in ambulation with a straight cane or no assistive device for ambulation, (4) Mini-Mental State Exam (MMSE) ≥ 24, (5) and written clearance of their physician to participate in low to moderate intensity, supervised exercise as is characteristic of interventions for improving walking. Characteristics of subjects are presented in Table 4-2.

Table 4-2: Demographic variables, mean (% of sample)

Average age	84 years
Race: White Black	33 (97%) 1 (3%)
Gender: Male Female	6 (18%) 28 (82%)
Education: High school or more College or more	33 (97%) 17 (50%)
Lives alone	28 (82%)
Mini-Mental State Exam	28.6
15-point Geriatric Depression Scale	2
Co-morbidity (total=8)	3.5

4.4 METHODS: MEASUREMENTS

4.4.1 Gait Classification System (Figure 1)

The observational gait classification system consisted of two components: consistency and posture, representing the components of movement control and biomechanical alignment. The movement control factor associated with the variability of stepping of gait, while the biomechanical factor associated with the posture of the body during gait. Subjects were assigned to one of the two variability gait patterns and one of the four postural patterns of gait.

To define the movement control component, the variability of gait was observed and individuals were classified as consistent or inconsistent based on the rhythmicity of stepping and walking path. Participants who walked with fluctuations in step length or step width, or demonstrated a deviated path, or unexpected trunk sway are classified as inconsistent.

Posture of the body, relative to the sagittal alignment of the body during the gait, was classified into one of four categories: usual, flexed, extended, and crouched. Individuals were classified to the flexed group if the head, shoulder, or trunk were anterior to a vertical line drawn through the hip joint to the ground. Individuals were classified to the extended group if the head, shoulder, or trunk were posterior to a vertical line drawn through the hip joint to the ground. Individuals classified into the crouched group were similar to those of flexed group, but with a flexed knee posture in addition to the head, shoulder and trunk position forward of the vertical.

4.4.2 Gait characteristics

Gait characteristics including gait speed, step length, step width, stance time, variability of step length, step width and stance time were used to compare means across gait patterns identified using the gait classification system. The spatial and temporal characteristics of gait were determined directly from the footfalls recorded on an instrumented walking surface, the GaitMatII™. The GaitMatII™ consists of a 4-meter long walkway, and a computer system for automated recording and storing of gait data derived from the opening and closing of the pressure sensitive switches in the walkway as the participant walks. In addition to the 4-meter long walkway, initial and final 1-meter non-instrumented sections are attached to allow the participant to accelerate and decelerate. Concurrent validity of GaitMatII™ has been previously determined by comparison of walking speed recorded using the GaitMatII™ to gait speed determined from a timed walk overground test; interclass correlation coefficient, 0.95.[8]

Gait speed was determined by dividing the time between the first and last switch closure by the distance traversed. Step length was determined as the distance between two consecutive footprints, measured from the heel of one footprint to the heel of next footprint. Step width was determined as the distance between the outermost borders of two consecutive footprints. Stance time was determined as the time period between the initial and the final foot contact with the floor of the same foot (the time to complete one step). The coefficient of variation (COV), SD/mean x 100 %, was used to quantify the variability of step length, step width and stance time. Previous studies have indicated a relation of gait variability among community-living older adults with a history of falls,[15 19] with muscle strength, balance, gait speed, physical function and mental health[15], and have indicated stride-to-stride variability to be an independent predictor of falling.[15 18 19]

4.4.3 Six-Minute Walk Test[76]

The Six-Minute Walk Test[76] of endurance was performed in an indoor mini-mall area of the senior continuing care residence, with a 150-foot long lap free from all obstacles. Heart rate and blood pressure were monitored before and after the test. Subjects were asked to cover as great a distance as possible during the allotted time, 6 minutes, with rest stops allowed as needed (time continued during the rest), the standardized encouragement every 30 seconds, and time remaining warnings as defined by Guyatt et al.[77] Subjects were accompanied throughout the entire walk. The total distance covered was recorded in feet and converted to meters for the data analyses.

4.4.4 Modified Gait Abnormality Rating Scale (GARS-M)[45]

The GARS-M, an observational rating of gait abnormalities associated with recurrent fall risk, was used to validate the proposed gait classification model. The GARS-M consists of 7 items related to timing and biomechanical aspects of posture during gait, and was derived from the original GARS[11] by VanSwearingen et al. in 1996[45]. The GARS-M has concurrent validity by comparison with measures of gait speed and stride length, construct validity for distinguishing between community-dwelling, frail older persons with and without a history of falls[45]and sensitivity (62.3%) and specificity (87.1%) for risk of recurrent falls, with a cutoff score of 9 for identifying at-risk older adults[10]. Established reliability of the GARS-M includes interrater reliability (Kappa coefficient [κ]=.97) and intrarater reliability (κ =.97) for total and item scores by an experienced observer[45].

4.4.5 Functional Status Questionnaire (FSQ)

The FSQ, a self-report measure of physical, psychological, and social role functions in patients who are ambulatory[78], was used to describe physical function. The FSQ includes questions about the amount of difficulty a person has completing a task during the past month. The 6 FSQ subscales can be used individually or as a composite[78], The basic activities of daily living (ADL) and instrumental activities of daily living (IADL) subscales were used in the study to quantify physical function. Subscale scores are transformed to a 0 to 100 scale, with lower scores representing greater limitations. The ADL and IADL subscales have demonstrated high internal consistency (α=0.79 and 0.82, respectively)[78]. The FSQ has also been shown to exhibit construct and convergent validity by comparison to health status measures such as reported bed disability days and restricted activity days[79 80].

4.5 METHODS: PROCEDURE

The gait classification system was validated by comparing differences in gait characteristics and ADL functions across gait patterns.

4.6 METHODS: DATA ANALYSIS

4.6.1 Multiple comparison tests

Multiple comparison tests were performed to validate the gait classification system by differences in gait characteristics and ADLs across gait patterns identified for the older adults. Comparisons were made between the consistent and inconsistent groups, and among the four groups defined by postural patterns within the consistent and within the inconsistent groups. A Student's T-test and Mann-Whitney test were used to compare 2 groups, and an ANOVA and

Kruskal-Wallis test were used as tests of overall significance for multiple comparisons. Fisher's LSD was used as a post-hoc test when the ANOVA was significant.

4.7 RESULTS

4.7.1 Consistent vs. inconsistent group

The results of multiple comparison tests are displayed in Table 4-3. Statistical difference was found for the GARS-M score. Further analysis revealed specific item differences between the consistent and inconsistent group for the GARS-M items "variability", "guardedness" and "total GARS-M" ($p<.05$). Mean gait speeds of subjects classified to the consistent and inconsistent group were mean (SD), 0.86 (0.21) m/s and 0.77 (0.22) m/s, respectively. Although the p-value is greater than 0.05, the mean difference between the consistent and inconsistent group was 0.10 m/s, which was greater than the substantial meaningful change (0.08 to 0.14 m/s) reported by Perera et al. in 2006.[71] Measures of variability appear greater in the inconsistent compared to the consistent group, but the differences were not significant.

Table 4-3: Means (SD) and Pair-wise between group comparisons between consistent and inconsistent gait pattern

Variables	Consistent Group (n=17)	Inconsistent group (n=17)	P value	Mean difference
Gait speed (m/s)	0.86 (0.21)	0.77 (0.22)	0.205	0.10
Step length (m)	0.49 (0.09)	0.46 (0.08)	0.270	0.04
Step length S.D.	0.03 (0.01)	0.04 (0.02)	0.288	-0.01
Step length variability (coefficient of variation, %)	7.09 (3.10)	8.96 (4.27)	0.199	-1.87
Step width (m)	0.23 (0.04)	0.23 (0.04)	0.725	-0.01
Step width S.D.	0.03 (0.01)	0.03 (0.01)	0.603	-0.00
Step width variability (coefficient of variation, %)	13.92 (6.06)	14.37 (6.94)	0.858	-0.44
Stance time (seconds)	0.80 (0.13)	0.84 (0.16)	0.397	-0.05
Stance time S.D.	0.04 (0.01)	0.06 (0.05)	0.196	-0.02
Stance time variability (coefficient of variation, %)	5.03 (0.82)	6.42 (3.62)	0.187	-1.39
Six-minute walk test (m)	235.28 (93.06)	262.21 (75.94)	0.435	-26.93
GARS-m total score (0-21)	3.76 (2.59)	5.88 (2.52)	0.029†	-2.12
FSQ: adl	90.20 (11.03)	91.67 (14.34)	0.455	-1.47
FSQ: iadl	76.27 (22.15)	76.53 (19.56)	1.000	-0.26

* significant in t-test; † significant in Mann-Whitney test

4.7.2 Consistent group: usual vs. flexed vs. extended vs. crouched

Among the subjects with consistent gait, the four groups defined by postural pattern differed in the 6-minute walk test (ANOVA, p<.05) (Table 4-4). Post-hoc tests for specific between group differences were not performed because of the insufficient subject numbers in the extended (n=0) and in the crouched (n=1) groups. The mean distance older adults with usual and flexed posture walked in 6 minutes were mean (SD), 175.87 (35.72) and 288.95 (73.25) meters, respectively (Table 4-4), indicating the older adults with flexed posture walked a longer distance than the ones with usual posture.

Mean gait speeds of subjects classified to the usual and flexed group were mean (SD), 0.92 (0.16) m/s and 0.86(0.23) m/s, respectively, a mean difference of 0.06 m/s. The difference is not significant, but greater than the value for a small meaningful change in gait speed (0.04 to 0.06 m/s) reported by Perera et al.[71]

Table 4-4: Results of ANOVA, Kruskal-Wallis test, or Chi-square test and means (SD) for 4 postural patterns within the consistent group

Variables	Usual (n=6)	Flexed (n=10)	Crouched (n=1)
Gait speed (m/s)	0.92 (0.16)	0.86 (0.23)	0.61
Step length (m)	0.52 (0.10)	0.49 (0.08)	0.39
Step length S.D.	0.03 (0.02)	0.03 (0.01)	0.04
Step length variability (coefficient of variation, %)	6.41 (2.74)	6.98 (3.30)	11.31
Step width (m)	0.23 (0.04)	0.23 (0.03)	0.21
Step width S.D.	0.03 (0.01)	0.03 (0.01)	0.04
Step width variability (coefficient of variation, %)	15.34 (7.47)	12.00 (4.86)	20.25
Stance time (seconds)	0.77 (0.09)	0.80 (0.16)	0.90
Stance time S.D.	0.04 (0.01)	0.04 (0.02)	0.05
Stance time variability (coefficient of variation, %)	5.09 (0.67)	4.98 (1.01)	5.13
Six-minute walk test (m)*	175.87 (35.72)	288.95 (73.25)	91.44
GARS-m total score (0-21)	3.17 (2.93)	3.80 (2.39)	7.00
FSQ: adl	92.59 (9.07)	90.00 (12.23)	77.78
FSQ: iadl	82.22 (17.21)	78.33 (18.09)	20.00

* significant in ANOVA; † significant in Kruskal-Wallis test; ¥ significant in chi-square test

4.7.3 Inconsistent group: usual vs. flexed vs. extended vs. crouched

Among the subjects with inconsistent gait, statistical differences were found between the 4 postural groups for step-width variability (ANOVA, $p<.05$), but not for other comparisons (Table 4-5). The mean differences between 4 postural groups were also examined (Table 4-6). The recorded value for gait speed was fastest in the older adults with extended posture, followed by the usual, flexed, and the crouched postural group. Older adults in the usual postural group walked the longest distance in 6 minutes, followed by the extended, flexed, and the crouched postural group. Although statistically insignificant, the mean differences between the 4 postural groups for gait speed and the Six-Minute Walk Test were greater than the meaningful changes reported by Perera et al. in 2006.[71]

Table 4-5: Results of ANOVA, Kruskal-Wallis test, or Chi-square test and means (SD) for 4 postural patterns within the inconsistent group

Variables	Usual (n=3)	Flexed (n=9)	Extended (n=3)	Crouched (n=2)
Gait speed (m/s)	0.78 (0.23)	0.75 (0.23)	0.87 (0.25)	0.65 (0.24)
Step length (m)	0.48 (0.07)	0.44 (0.09)	0.51 (0.08)	0.40 (0.10)
Step length S.D.	0.03 (0.01)	0.04 (0.02)	0.05 (0.00)	0.05 (0.00)
Step length variability (coefficient of variation, %)	5.74 (1.58)	8.75 (5.08)	10.22 (1.80)	12.76 (3.98)
Step width (m)	0.21 (0.03)	0.24 (0.05)	0.24 (0.03)	0.20 (0.00)
Step width S.D.	0.05 (0.02)	0.03 (0.01)	0.03 (0.01)	0.03 (0.01)
Step width variability (coefficient of variation, %)*	24.11 (10.57)	11.05 (3.82)	12.74 (1.46)	15.46 (3.00)
Stance time (seconds)	0.94 (0.34)	0.85 (0.11)	0.75 (0.12)	0.83 (0.08)
Stance time S.D.	0.09 (0.09)	0.05 (0.03)	0.06 (0.04)	0.04 (0.00)
Stance time variability (coefficient of variation, %)	8.20 (5.84)	5.78 (3.28)	7.33 (4.08)	4.97 (0.59)
Six-minute walk test (m)	342.90 (32.33)	241.44 (75.42)	297.18 (60.48)	182.88
GARS-m total score (0-21)	5.33 (3.22)	6.11 (1.90)	4.33 (4.04)	8.00 (1.41)
FSQ: adl	96.30 (6.42)	92.59 (7.86)	81.48 (32.08)	100.00
FSQ: iadl	90.00 (8.82)	76.91 (19.91)	59.63 (21.95)	83.33

*significant in ANOVA; † significant in Kruskal-Wallis test; ¥ significant in chi-square test

Table 4-6: Mean differences in gait speed and 6-minute walk test between 4 postural patterns within the inconsistent group

	Mean difference between groups					
Variables	U vs. F	U vs. E	U vs. C	F vs. E	F vs. C	E vs. C
Gait speed (m/s)	0.03	-0.09¥	0.13¥	-0.12*	0.10¥	0.22¥
Six-minute walk test (m)	101.46¥	45.72¥	160.02¥	-55.74¥	58.56¥	114.3¥

* Greater than the reported small meaningful changes. ; ¥ Greater than the reported substantial meaningful changes.
Small meaningful change for gait speed is 0.04 to 0.06 m/s. Substantial meaningful change for gait speed is 0.08 to 0.14 m/s.
Small meaningful change for 6-minute walk test is 19 to 22 m. Substantial meaningful change for 6-minute walk test is 47 to 49 m.

4.8 DISCUSSION

In order to quickly identify and classify older adults with mobility problems in clinical settings, an observational gait classification was developed and tested. The classification system was previously validated in 106 male veterans using GARS-M items, gait parameters and physical performance test. The study was designed to further validate the classification system in a different population consisting of both genders using gait characteristics including gait speed, step length, step width, stance time and the variability measures, six-minute walk test, GARS-M and FSQ.

The small sample size (n=34) may have been a major factor in the ability to detect statistical differences among groups classified based on movement control (consistent and inconsistent) and biomechanical (usual, flexed, extended, crouched) factors. However, we were able to validate the gait classification system by comparing the mean differences between groups with the meaningful change estimates for gait speed and Six-Minute Walk Test reported by Perera et al. in 2006.[71] For gait speed, the small meaningful change estimates ranged from 0.04 to 0.06 m/s and the substantial change estimates ranged from 0.08 to 0.14 m/s.[71] For 6-minute walk test, the small meaningful change estimates ranged from 19 to 22 m and the substantial change estimates ranged from 47 to 49 m.[71]

4.8.1 Gait speed as a differentiating factor among groups

Gait speed has been identified as a predictor of ADL and mobility disability outcomes in community-dwelling older adults[12] and decreased gait speed is associated with increased age[13 14], gait variability[15], decreased hip and knee flexion range[13], increased risk of falls[16] and several medical conditions such as arthritis, diabetes mellitus, stroke, and peripheral vascular disease[13]. In our study, the mean difference of gait speed was 0.10 m/s with the consistent and inconsistent group walked at the mean speed of 0.86 m/s and 0.77 m/s, respectively. Since the mean difference was greater than the substantial change estimate, the difference of gait speed between the consistent and inconsistent groups suggested that the inconsistent group were at greater risks of ADL and mobility disability. Probabilities of developing disability in mobility and ADL over 1 year and 4 years according to age, sex, and gait speed were calculated based on the equations provided by Guralnik et al.[12] Results are presented in Appendix B. Older adults with inconsistent gait were more likely to develop disability. However, the differences between the consistent and inconsistent group were greater in males.

Within the consistent group, there were no older adults with extended posture, and one older adult with crouched posture. Therefore, the comparison was only made between the usual and the flexed group. The mean difference of gait speed between the usual and the flexed postural pattern (0.06 m/s) was greater than the small change estimate.[71] Within the inconsistent group, the mean differences of gait speed between the four postural groups (Table 4-6) were greater than the small or the substantial change estimate except for the difference between the usual and the flexed group. The differences of gait speed between the postural groups suggested that the risks of ADL and mobility disability might be different among the groups. Probabilities of developing disability in mobility and ADL over 1 year and 4 years among older adults with consistent and inconsistent gait were calculated according to age, sex, and gait speed based on the equations provided by Guralnik et al.[12] Results are presented in Appendix C. When comparisons were made among 4 postural groups, only data from the female subjects were included in the calculation because of the few number of male subjects (no male subjects in consistent/extended, consistent/crouched, inconsistent/usual, inconsistent/extended, inconsistent/crouched). Within both consistent and inconsistent groups, older adults with the crouched posture were more likely to develop disability in comparison with those with usual, flexed, and extended posture (Appendix B). Results from our study suggested that classifying older adults based on the movement control (consistent vs. inconsistent) and biomechanical (usual, flexed, extended, crouched) factors might be helpful in identifying older adults at greater risk of ADL and mobility disability.

4.8.2 Step length, step width, stance time, and variability measures as differentiating factors among groups

In our study, no statistical differences were found in step length, step width, stance time, and the variability measures between the groups classified using the gait classification except for step-width variability differing between the usual and flexed, and the usual and extended postural groups within the inconsistent group. Within the inconsistent group, step-width variability of the usual postural group was greater than that of the flexed and the extended group. In 2001, Brach et al. found a negative correlation between mean walking speed and mean step width and suggested that the slower the gait speed, the less variable the step width.[8] With step-width variability possibly being a measure of dynamic balance, a greater step-width variability at faster gait speeds may be one mechanism by which older adults are able to maintain their physical function.[8] A lesser step-width variability at slower speeds may indicate loss of ability to maintain the dynamic balance. The older adults with usual posture are expected to have better control of dynamic balance. In our study, the step-width variability was greater in the usual group. Therefore, our results suggested that it is possible to identify older adults with greater step-width variability, thus possibly better dynamic balance control with the gait classification system.

Since there is no reported meaningful change estimates for step length, step width, stance time and the variability measures, we were unable to quantify the significance of the differences with a small sample size. Although the values were not different, the older adults classified to the inconsistent group walked with a shorter step length, greater step-length variability, longer stance time, and greater stance-time variability. Within the consistent group, the older adults with usual posture walked with longer step length and lesser step-length variability. Within the inconsistent group, the usual group walked with lesser step length variability and greater step-width variability.

4.8.3 Six-Minute Walk Test as a differentiating factor among groups

The Six-Minute Walk Test is used as a measure of exercise tolerance and endurance for community dwelling older adults.[73 76] The Six-Minute Walk Test has been used to describe and monitor an individual's endurance level.[73 76] We expected that the older adults with inconsistent gait and deviated postural patterns walked a shorter distance. However, in our study, no statistical difference was found between the consistent and inconsistent group. The older adults in the inconsistent group walked longer distance than the ones in the consistent group (26.93m; greater than the small meaningful change reported). It is possible that the difference between the 2 groups is not meaningful because the difference is statistically insignificant and only slighter higher than the small meaningful change reported (19 to 22 m).[71] Among the 34 older adults, 26.5% of Six-Minute Walk Test data were missing. The percentages of missing data within the consistent and inconsistent group were, 41.2% and 11.8%, respectively. The small meaningful difference between the consistent and inconsistent group may not be meaningful because of the considerably unequal missing data rates between the two groups. In order to examine the impact of postural patterns on Six-Minute Walk Test result, it is more reasonable to look at the comparisons among 4 postural patterns in the inconsistent group due to the much higher missing data rate within the consistent group. Within the inconsistent group, the older adults with the usual posture walked the longest distance in 6 minutes, followed by the extended, the flexed, and the crouched postural group (Table 4-5 & 4-6). The differences across postural patterns (Table 4-6) were greater than the substantial meaningful change reported (47 to 49 m).[71] We may suggest that the level of exercise tolerance and endurance in older adults with usual posture are greater than the ones with the extended, the flexed, and the crouched posture.

4.8.4 GARS-M as a differentiating factor among groups

The lower the GARS-M score, the better the performance. In our study, the mean total GARS-M score was mean (SD), 3.76 (2.59) in the consistent group and 5.88 (2.52) in the inconsistent group ($p<.05$). Given the relation of the GARS-M to the identification of fall-risk, the individuals classified to the inconsistent group in our study we assume are more likely to fall and may benefit from a fall prevention program. Within both consistent and inconsistent groups, mean total scores of the GARS-M among the four postural groups was not significantly different from each other. However, the crouched group scored the highest, followed by the flexed and the usual groups. A larger sample size would be important to determine if significant differences would be detected.

4.8.5 FSQ as a differentiating factor among groups

No differences in the FSQ were found between groups. Relations between ADLs and IADLs and the gait patterns identified by the gait classification system are not conclusive from our results. The participants for the study, although community dwelling oldler adults, reside in a setting that may positively impact physical function in everyday life. The environment includes a number of long indoor corridors with handrails a long the walls throughout. The residents' live in apartments and townhouse homes independently, but meals are served in the dining room, and housekeeping staff provide the major cleaning for the residences, leaving only snacks and very light cleaning activities for the resident to complete. Though residents can freely leave and return to the campus of the senior residence, many use the valet transportation provided for them to go shopping, to social events and appointments. Thus, reports of ADLs and particularly IADLs may be influenced by the environment and resources of the senior community residence and not represent the ability or even the older adults' perception of their abilities if they lived in an individual residence in the community without the support described above.

4.8.6 limitations

Despite the limitation of a small sample size, meaningful changes could be demonstrated for gait speed and the 6-minute walk test, yet the statistical results were not significant. In order to detect a small meaningful change between 2 groups in gait speed (0.05 m/s) with 80% power, the estimated number of subjects needed per group is 90.[71] According to our clinical observation, the proportions of consistent and inconsistent gait among older adults reported mobility problems are close. However, it is much less frequent to see older adults with the extended posture. The majority of older adults reported mobility problems walked with a flexed posture. Due to the unequal distribution of the 4 postural patterns, the total sample size will be over 360 in order to include enough subjects in the extended group.

4.8.7 Future direction

The results from the study further validated the gait classification system. Although the statistically tests were mostly insignificant, we could still conclude that the gait classification system was validated because the gait classification has been previously validated in a larger sample and the statistical differences in GARS-M and step-width variability and meaningful changes in gait speed were found in the current study. Since the inter-rater reliability is high for gait classification, we also believed that the patterns could be recognized by therapists in clinical settings. The gait classification system could be used to identify older adults with gait problems. Future evaluation of the gait classification system, by targeting interventions for specific patterns of deficits in movement control and biomechanical components of gait characteristic of the classification may enhance the management of gait problems in older adults.

5.0 CONCLUSION

The relations of gait with falls, physical function and ADLs, and the lack of an observational gait classification system for older adults magnify the importance of developing a clinically feasible classification system appropriate for identifying specific gait patterns. Gait patterns of older adults, based on biomechanics and movement control were reliably recognized and validated by differences in gait characteristics and physical function tests across patterns. In phase one analysis, the interrater and intrarater reliability were established. We assume clinicians with similar background and experience will be able to use the gait classification system with similar results.

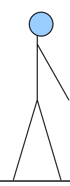
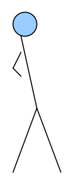
The observational gait classification system was first validated using GARS-M items and total score in phase one analysis. In phase two analysis, the concurrent validity of the gait classification system was validated using gait characteristics and PPT. Gait patterns identified by movement control (consistent and inconsistent gait) differed from each other in GARS-M, gait speed, step length, step length variability and PPT score. Within both consistent and inconsistent group, postural patterns identified by biomechanical component (usual, flexed, extended, crouched) differed from each other in GARS-M, gait speed, step length, and PPT score except for the extended postural group. Small number of sample size in the extended group (n=5 in consistent group, n=2 in inconsistent group) might be a limiting factor in detecting statistical differences. Although the extended posture can be observed clinically, we were unable to differentiate the extended posture from other postural groups. In phase three analysis, sample size may be a primary limiting factor in detecting statistical differences between groups. We were able to validate gait patterns identified by movement control component using GARS-M. Mean differences of gait speed and Six-Minute Walk Test between groups were greater than the meaningful change reported by Perera et al.[71] between consistent and inconsistent group and among the four postural groups.

The results from our study can be used to support the concept that variability and three postural patterns (usual, flexed, crouched) of gait can be determined by observation of gait by physical therapists. The extended posture was not validated in this study due to the inconclusive findings and small number of subjects in three phases of analyses. Based on the clinical observation, older adults with extended posture usually have restricted upper extremity movement with one or two arms posterior to the trunk. This may limit the amount of forward momentum and disrupt the inverted pendulum mechanism[46]. The role of extended posture needs to be further examined if more subjects were available.

The observational gait classification will potentially be useful in targeting interventions for specific deficits of movement control and biomechanical components of gait. Exercise programs including treadmill training and practice of stepping components which enhances a regular stepping pattern may be viable options to reduce gait variability in older adults with movement control problems. Interventions targeting for the specific biomechanical deviations may be helpful to restore the postural pattern. Stretching hip flexors may reduce the amount of anterior pelvic tilt, increase the step length, and enhance the more erect trunk posture.[25] Strengthening exercise for lower extremity muscles may be effective in helping older adults negotiate environmental gait challenges.[49] In the future, this observational classification of gait patterns can be evaluated for value in targeting interventions based on specific deficits of gait in older adults with mobility problems.

APPENDIX A

GAIT CLASSIFICATION SYSTEM SCORING SHEET

Movement control		Biomechanical pattern			
Consistent	**Inconsistent**	**Usual** 	**Flexed** 	**Extended** 	**Crouched** 

APPENDIX B

PROBABILITIES OF DEVELOPING DISABILITY IN MOBILITY AND ADL OVER 1 YEAR AND 4 YEARS ACCORDING TO AGE, SEX, AND GAIT SPEED: CONSISTENT VS. INCONSISTENT GROUP

	Consistent		Inconsistent	
	Male	Female	Male	Female
1-year mobility disability	0.109	0.188	0.237	0.193
1-year ADL disability	0.025	0.039	0.069	0.040
4-year mobility disability	0.223	0.378	0.399	0.383
4-year ADL disability	0.089	0.119	0.209	0.122

Calculations based on the equations provided by Guralnik et al.[12]

APPENDIX C

PROBABILITIES OF DEVELOPING DISABILITY IN MOBILITY AND ADL AMONG FEMALE OLDER ADULTS OVER 1 YEAR AND 4 YEARS ACCORDING TO AGE, SEX, AND GAIT SPEED: AMONG 4 POSTURAL GROUPS

	Consistent Female			Inconsistent Female			
	Usual	Flexed	Crouched	Usual	Flexed	Extended	Crouched
1-year mobility disability	0.158	0.181	0.377	0.237	0.201	0.104	0.285
1-year ADL disability	0.030	0.037	0.116	0.056	0.042	0.016	0.071
4-year mobility disability	0.330	0.366	0.613	0.455	0.394	0.227	0.504
4-year ADL disability	0.095	0.113	0.299	0.165	0.128	0.053	0.200

Calculations based on the equations provided by Guralnik et al.[12]

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