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An observational treatment-based gait pattern classification method for targeting interventions for older adult males with mobility problems: Validity based on movement control and biomechanical factors

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ABSTRACT

Background: A reliable and valid observational gait assessment intended to guide clinical intervention for gait deficits in older adults has not been proposed. A quick gait classification method which tailors clinical management for different patterns of gait dysfunction may be useful for clinicians with limited access to apply computer-assisted gait analyses.
Research Question: This work aims to establish reliability and validity of the Treatment-Based Gait Pattern Classification (TBGPC) that can be used to quickly identify and classify mobility problems of older males, and possibly target interventions for specific gait deficits in clinical settings.
Method: Videotapes of 116 older male veterans referred for mobility problems were analyzed in this cross-sectional study. The TBGPC defined by movement control (consistent, inconsistent) and postural biomechanical factors (usual, flexed, extended, crouched) was validated by comparing means of individual items of the Modified Gait Abnormality Rating Scale (GARS-M) across groups.
Results: Kappas for interrater reliability of the TBGPC movement control and biomechanical components were 0.59 and 0.75, respectively; for intrarater reliability, 0.82 and 0.72, respectively. Both movement control and biomechanical components were validated. All GARS-M items were different between older males with consistent and inconsistent gait. Within the consistent and inconsistent group, hip ROM was one of the most differentiating GARS-M item between older males with usual and flexed gait and flexed and crouched group. Total GARS-M score and guardedness were two differentiating factors between the usual and crouched group.
Significance: Gait patterns of older males were reliably recognized and validated by mean differences in abnormal characteristics of gait across patterns. The TBGPC may be useful to quickly identify and classify mobility problems of older males and to guide clinical intervention.

1. Introduction

Gait changes in older adults have been proven to be related to ADL disability [1–3] and increased fall risks [4–7]. Identification of gait changes in clinical settings allows clinicians to provide early interventions which may prevent future disability and falls in older adults. While computer-assisted gait analyses provide specific and detailed data of gait deviations, observational gait analyses provides a quick, often easier to implement, and inexpensive method to capture gait deficits in clinical settings.

Observational gait analysis is a common method used in clinical setting [8], and several scales such as Rancho Los Amigos Observational Gait Analysis Scale [9] and Rivermead Visual Gait Assessment [10] have been proposed. Most observational gait analysis scales have fair to moderate inter-rater reliability and concurrent validity, and moderate to substantial intra-rater reliability [9–11]. However, at present, a treatment-based classification method intended to guide clinical intervention for specific gait deficits in older adults with mobility problems has not been proposed. A classification method of gait pattern disorders may facilitate a targeted intervention approach for specific deficits of motor control and biomechanical components of gait.

Based on reported research and clinical experience in mobility assessment of older adults, an observational gait classification method was proposed to identify gait deviations by movement control factors and biomechanical factors [5,7,12–15]. Movement control and biomechanical factors were included in the classification because of the

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potential of targeted interventions for variability and postural components of gait to improve walking [16–19]. Older adults with movement control problems may benefit from exercise programs aiming to enhance the automatic repeated stepping pattern. A previous pilot study found treadmill walking decreased gait variability [16]. Hausdorff et al. [17] found an strengthening and balance exercise training reduced stride time variability by 50%. Older adults with biomechanical problems (postural deviations) also benefit from exercise programs. Gait characteristics of female subjects with kyphotic posture improved after a 4-week exercise program [19]. Dynamic peak hip extension and ankle plantar flexion of older adults increased after a 12-week hip flexor stretching program [18].

The purpose of the present study was to classify gait patterns of older adult males by clinical observation of movement control and biomechanical factors (the Treatment-Based Gait Pattern Classification, TBGPC), and to determine characteristics of gait that define differences among the patterns. The proposed gait patterns are expected to be differentially represented in older adults with walking difficulty.

2. Methods

2.1. Proposed gait classification system (Fig. 1)

Based on reported research and clinical experience in the observation of older adults walking, we proposed a gait pattern classification method (the TBGPC), which includes the observation of two general components of gait, movement control factors (two patterns of variability) and biomechanical factors (four postural patterns) [5,7,12–15]. The movement control factor is associated with gait variability, which has previously been identified as a significant factor associated with an increased fall risk [4,5,7]. 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 is a marker of a more general decline in motor control and balance [7]. The biomechanical factor is associated with the posture of the body during gait, which has previously been related to slower gait speed [12,14], increasing base of support [12,14], slower up and go (TUG) [14] and shorter distance on functional reach [14].

2.1.1. Movement control factor

In TBGPC (Fig. 1), the movement control component is classified by the consistency of repeated stepping pattern and the smooth, continuous translation of the body along the walking path observed during gait. Participants observed to walk with fluctuations in step lengths or step widths, deviated path, or unexpected trunk sway classified as inconsistent. Fluctuation of step lengths defined as unequal right and left step lengths accompanied with inconsistent differences between right and left step lengths throughout consecutive stepping cycles. Fluctuation of step widths defined as inconsistent step widths observed during gait. Deviated path defined as the observed excursion from the intended line of progression of the walking path, including steps crossing over or veering from the intended path. Unexpected trunk sway was defined as inconsistent and unexpected trunk movement during walking, with the observation of unexpected anterior, posterior, or lateral trunk sway.

2.1.2. Biomechanical factor

In TBGPC (Fig. 1), the posture of the body during the gait was classified into one of four categories: usual, flexed, extended, or crouched. The posture is determined by observation of the sagittal alignment of the body during gait. Individuals were classified as “flexed” if the head, shoulder, or trunk were anterior to a vertical line drawn through the hip joint to the ground. Individuals were classified as “extended” if the head, shoulder, or trunk were posterior to a vertical line drawn through the hip joint to the ground. Individuals classified as “crouched” 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.

Combinations of movement control and biomechanical factors yield eight gait patterns of the TBGPC system (Fig. 1): consistent/usual, inconsistent/usual, consistent/flexed, inconsistent/flexed, consistent/extended, inconsistent/extended, consistent/crouched, and inconsistent/crouched.

2.2. Procedures

The study was designed to evaluate the reliability and validity of the newly developed observational TBGPC. Videotapes of older adult walking, collected as a part of a clinical assessment and management of community-dwelling older adults to determine gait abnormalities, were used. In the beginning of the study, a senior physical therapist with more than 20 years of clinical experience introduced the concept of the TBGPC to two physical therapists involved in scoring. Two physical therapists, with three and five years of experience, respectively, individually scored videotapes of 4 sample subjects. The results were compared and the discrepancies discussed. To evaluate inter- and intra-rater reliability of the gait classification system, videotapes of a subset of the sample (n = 34) were evaluated independently by two physical therapists, with one rater repeating the ratings about 3 months later. To evaluate validity, videotapes of all the older adults (n = 106) were

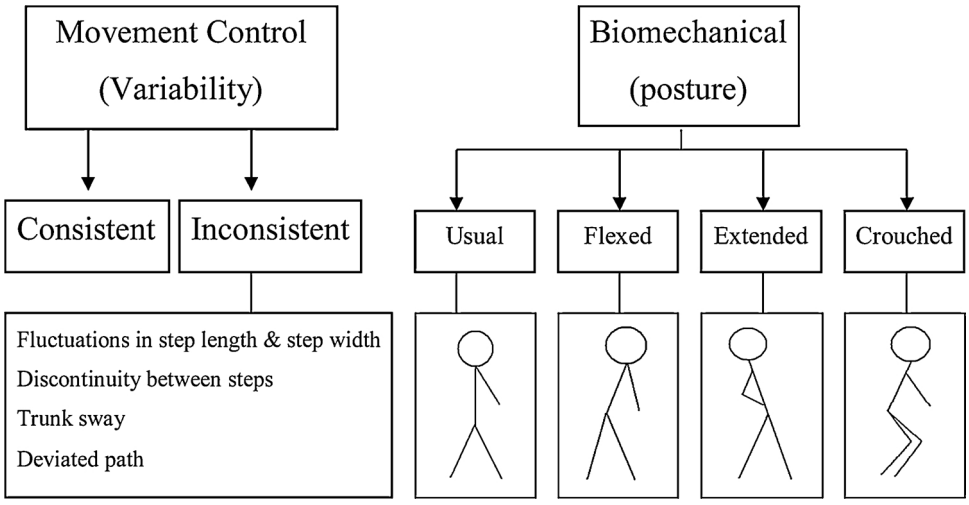

Fig. 1. Treatment-Based Gait Pattern Classification, TBGPC.

Table 1
Frequency and Age of Older Adults by Gait Pattern.

Gait Pattern (Movement Control Factor)	Number of subjects	Gait Pattern (Postural Factor)	Number of subjects	Mean Age (SD)	Mean Gait Speed
Consistent	59	Usual	7	71 (6)	0.94 (0.31)
		Flexed	41	76 (8)	0.65 (0.29)
		Extended	5	74 (3)	0.55 (0.14)
		Crouched	6	81 (4)	0.48 (0.24)
Inconsistent	47	Usual	5	72 (10)	0.67 (0.23)
		Flexed	33	77 (7)	0.50 (0.23)
		Extended	2	77	0.44
		Crouched	7	81 (2)	0.29 (0.19)

reviewed and classified using the TBGPC by one physical therapist. The same videotapes were reviewed by the senior physical therapist using the established observational rating scale, the modified Gait Abnormality Rating Scale (GARS-M) [20]. The Institutional Review Board of the University of Pittsburgh approved the use of the videotapes to validate the treatment-based gait classification. This is secondary data use of the collection of videotapes; the videos a part of a clinical database established in the early 1990s.

2.3. 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. Nonambulatory older veterans and those with severe dementia or acute terminal illness were generally not seen by the GEM Program team. The older veterans included were independent in ambulation and used a cane or no assistive device for walking. The videotapes from each subject's first clinic visit was used (n = 108). The sample of veterans studied was overwhelmingly male, and thus 2 female veterans were excluded to achieve a homogeneous sample of 106 male veterans (mean age, 76; SD, 7.1; range, 63–97 years). The first 1/3 of the sample were used for reliability (n = 34).

2.4. 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 to rate abnormalities of stepping and postures of gait [20]. 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 and without a history of falls [20]. Sensitivity (62.3%) and specificity (87.1%) with a cutoff score of 9 for risk of recurrent falls has been determined [21]. Concurrent validity of the GARS-M was demonstrated by comparison with quantitative measures of gait speed and stride length. The GARS-M has demonstrated excellent interrater reliability (Kappa coefficient [κ] = .97) and intrarater reliability (κ = .97) [20].

2.4.2. Treatment-Based Gait Pattern Classification, TBGPC (Fig. 1)

The proposed observational gait classification system (TBGPC) 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. Data analysis

2.5.1. Reliability

Ratings using the gait classification system were recorded by two therapists independently at different times and places (for interrater reliability). Repeated ratings by one therapist were recorded 3 months later (for intrarater reliability). Kappa statistic was used to describe interrater and intrarater reliability of the gait classification system, by determining agreement for the two components, 1) consistency (consistent, inconsistent), and 2) posture (usual, flexed, extended, crouched). Altman [22] suggests the following interpretation of Kappa for agreement: poor ≤ 0.20; fair = 0.20 to 0.40; moderate = 0.40 to 0.60; good = 0.60 to 0.80; very good = 0.80 to 1.00.

2.5.2. Validity

The gait classification system was validated by comparing the distribution of the mean scores of the 7 GARS-M items across the gait patterns. Kruskal- Wallis test was used to compare GARS-M item scores across multiple consistency and postural groups. A Mann-Whitney *U* test with two-tailed *p*-value was performed to validate the gait patterns by pairwise comparison of the scores of the 7 GARS-M items across the two gait consistency patterns and four postural groups.

3. Results

The frequencies of classification categories and age distributions of 106 older males are shown in Table 1. More subjects were classified to consistent (n = 59) than the inconsistent group (n = 47). The distribution of postural patterns was uneven with majority of older adults classified to flexed postural group.

3.1. Reliability

Interrater reliability for the two raters for the components of gait patterns, consistency and posture, as measured by Kappa statistic for agreement, were 0.59 and, 0.75 respectively. Intrarater reliability for one rater for the two components, Kappa statistics were 0.82 and 0.72, respectively.

3.2. Validity: gait pattern component: consistency (Table 2)

Based on comparison of mean ranks across the gait patterns, consistent and inconsistent groups were significantly different ($p < 0.05$) for the total GARS-M score and for all individual GARS-M items. Older adults with consistent gait pattern performed better on the GARS-M items related to the temporal aspects of gait, such as "Variability," "Arm-heelstrike synchrony" and "Staggering" with lower the scores representing better performance.

3.3. Validity: gait pattern component: postural patterns within the consistent group

Among the four postural patterns within the consistent group, total GARS-M score and all GARS-M items except "Staggering" were different across groups (Kruskal-Wallis test, $p < 0.05$). Three distinct postural patterns, usual, flexed and crouched, were identified by comparing the mean ranks in GARS-M items across the four proposed patterns. Comparisons between pairs of postural groups, except the flexed vs

Table 2
Means & Between-Group Differences by GARS-M Items for Older Adults Classified by Movement Control Factor.

GARS-M items	Mean Value (SD)		Between Group Comparisons (Mann-Whitney Test)
	Consistent (n = 59)	Inconsistent (n = 47)	*p*-Value
Variability	0.68 (0.78)	1.66 (0.76)	.000*
Guardedness	0.95 (0.94)	1.83 (0.82)	.000*
Staggering	0.02 (0.13)	0.17 (0.56)	.047*
Foot Contact	1.20 (1.20)	2.09 (1.16)	.000*
Hip ROM	0.76 (1.07)	1.47 (1.10)	.001*
Shoulder Extension	1.29 (0.97)	1.70 (1.14)	.046*
Arm Heelstrike Synchrony	0.93 (1.13)	1.74 (1.21)	.001*
GARS-M total score	5.83 (4.90)	10.66 (4.97)	.000*

* Mann–Whitney Test of differences ($P < .05$).

extended comparison, differed in GARS-M item scores (Fig. 2). Specifically, older males with usual and flexed postural patterns and older males with usual and crouched postural patterns were different in all GARS-M items except "staggering" (Fig. 2). Older males with usual and extended postural patterns were different in "variability" and "ankle-heel strike synchrony" (Fig. 2). Older males with flexed and crouched postural patterns were different in "Guardedness", "Hip ROM" and "Arm Heelstrike Synchrony", with the "Hip ROM" the most distinguishing factor (Fig. 2).

3.4. Validity: gait pattern component: postural patterns within the inconsistent group

Within the inconsistent group, total GARS-M score and GARS-M items "foot contact" and "hip ROM" were different across groups (Kruskal-Wallis test, $p < 0.05$). Three distinct postural patterns, "Usual", "Flexed" and "Crouched", were identified by comparing the mean ranks in GARS-M items across the four proposed patterns. By paired comparisons, the four postural patterns differed from each other in at least one GARS-M item, except between the usual and the extended patterns (Fig. 3). "Hip ROM" was the most distinguishing factor between the usual and flexed groups, the usual and crouched groups, and between the flexed and crouched groups (Fig. 3). "Foot contact" and "hip ROM" items were different between the extended and crouched groups (Fig. 3). "Foot contact" was the only distinguishing factor between the flexed and extended groups (Fig. 3).

4. Discussion

In this study, we classified gait patterns of older males with mobility problems using structured clinical observation and compared the classification to an established gait assessment tool, based on specific characteristics of gait [20,23]. 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 males walking.

Older males with consistent and inconsistent gait were different for all individual GARS-M items and the total GARS-M score. The most differentiating GARS-M items between the consistent and inconsistent gait patterns were "Variability," "Guardedness" and "Foot contact." Individuals with a higher score in "Variability" presented greater arrhythmicity in the temporal control of the gait, such as the stepping and arm movement. The increased variability during walking may be a manifestation of impaired motor control, reflected in errors in control of foot placement and/or the center-of-mass [7]. The higher "Guardedness" score suggests greater hesitancy, slowness, diminished propulsion and lack of commitment in stepping and arm swing. The center of gravity of head, arms, and trunk (HAT) may shift forward or backward with greater tentativity in stepping. Changes in the HAT position may be a strategy to maintain balance during walking. 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. The usual automatic stepping mechanism may be substituted by the more voluntary control of foot placement.

Older adults were classified to one of the four postural groups based on the biomechanical alignment observed during walking. Within both consistent and inconsistent groups, "Hip ROM" was one of the most differentiating GARS-M items between older adults with the usual and flexed gait patterns, and between the flexed and crouched groups. Hip extension during walking is associated with shortened contralateral

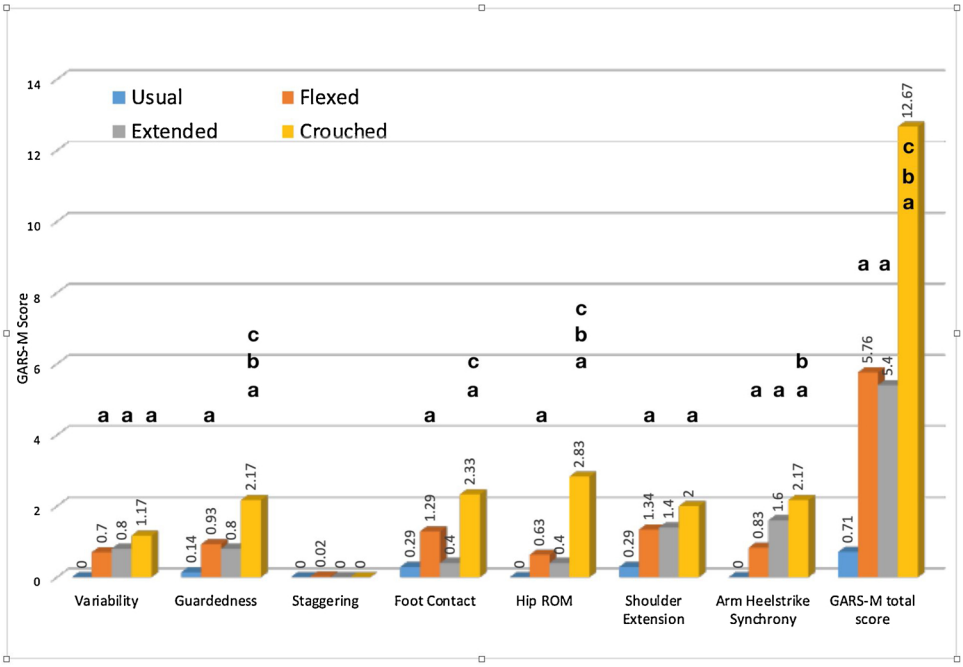

Fig. 2. Means and Pair-wise Comparisons of GARS-M Items across Postural Patterns within Consistent Group. a Mann–Whitney Test of differences between usual posture and other postures ($P < .05$). b Mann–Whitney Test of differences between flexed posture and extended, crouched postures ($P < .05$). c Mann–Whitney Test of differences between extended posture and crouched postures ($P < .05$).

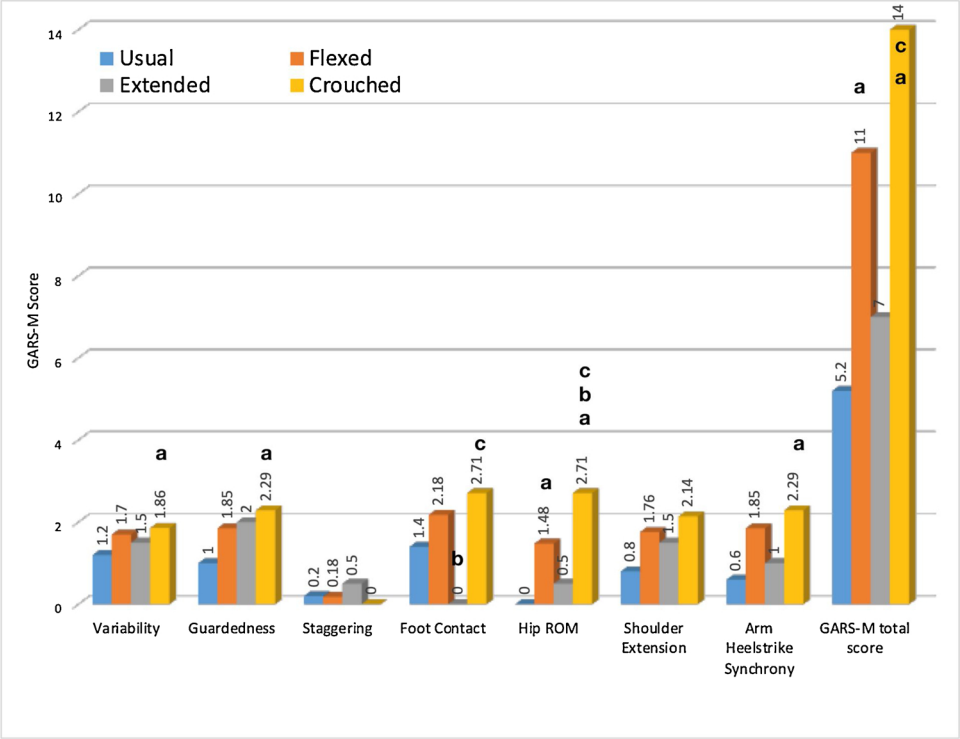

Fig. 3. Means and Pair-wise Comparisons of GARS-M Items across Postural Patterns within Inconsistent Group. a Mann–Whitney Test of differences between usual posture and other postures ($P < .05$). b Mann–Whitney Test of differences between flexed posture and extended, crouched postures ($P < .05$). c Mann–Whitney Test of differences between extended posture and crouched postures ($P < .05$).

step length and slower gait speed [24], and has been found to differentiate elderly fallers from the non-fallers [25]. Reduced hip extension will likely propagate a walking disability followed by insufficient momentum of propulsion. Within both consistent and inconsistent groups, "Guardedness" and total GARS-M score were two differentiating factors between the usual and crouched group. A higher score in "Guardedness" usually indicates the anterior placement of center of gravity of HAT. The crouched group is characterized by forward bended trunk with decreased shoulder extension and hip extension during push off. The total GARS-M score has been found to be associated with risk of recurrent falls [20], and slower walking speed [20]. The crouched group is expected to have 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, those with extended posture (n = 5) were not different from those with flexed posture. Within the inconsistent group, those with extended posture (n = 2) were not different from the usual group within the inconsistent group. The extended postural group needs to be further studied with more subjects.

Although gait patterns of older adults with mobility problems differ, interventions for improving walking vary little [17,18,26]. The movement control and biomechanical components were two common approaches clinicians used to improve walking in older adults with mobility problems, and previous studies provide evidence for both approaches [17–1927]. Motor control component, presented as gait variability during walking, can be improved by treadmill [17,27], strengthening or balance training [26], or timing and coordination exercise for walking [28,29]. Biomechanical component, presented as postural deviations, can be improved with appropriate exercise intervention targeted for impairments of joint range of motion, muscle force, or ambulation training to correct posture during gait [18,25]. Individuals classified as having flexed and crouched posture are likely to benefit from exercise program designed to improve hip extension during walking [25]. Individuals classified as having crouched posture may benefit from exercise program designed to improve shoulder and hip extension. While we were unable to validate the extended group due to the few number of participants classified as extended, from the observations recorded, we hypothesized that the extended posture may be improved by hip extensor strengthening exercise.

Different from other gait evaluation tools, TBGPC aims to specifically help clinicians determine whether an individual is in need of interventions to improve his/her motor control and biomechanical component of gait. Most of the existing gait evaluation tools are extremely valuable in providing detailed and comprehensive evaluation of gait. However, an extensive background and professional expertise are usually required to complete the evaluations. For example, Rancho Los Amigos Observational Gait Analysis Scale [30] and Rivermead Visual Gait Assessment [10] provide comprehensive and detailed evaluations of the trunk and the lower extremity movement during a full gait cycle in people with neurologic and orthopedic deficits. We expect the TBGPC does not require extensive background and experience in gait analysis. Clinical practitioners including physical therapists and other allied health professionals can be trained to use the TBGPC to identify older males with mobility problems. Based on Altman's interpretation of Kappa [22], the TBGPC has relatively good reliability: moderate to good interrater and good to very good intrarater reliability. For comparison, Rancho Los Amigos Observational Gait Analysis Scale reported reliability, fair to moderate interrater and moderate to good intrarater reliability [30].

The GARS-M items were the only variables used to validate the TBGPC. In the future, other gait characteristics, physical function measures, and medical diagnoses would be useful to further validate and define the usefulness of the TBGPC for prognosis and treatment planning. The study is limited by inclusion of only older males. Future studies including older females and incorporating treadmill training targeted for deficits of movement control and exercise targeted for specific impairments associated with the postural changes are needed to confirm the clinical usefulness of the gait classification system.

5. Conclusion

Gait patterns of older adults, based on movement control and biomechanical factors, were reliably recognized and validated by mean differences in abnormal characteristics of gaits across patterns. The

TBGPC may be useful to quickly identify and classify gait deficits, and to guide clinical intervention among older adults with mobility problems.

Conflicts of interest and source of funding

All authors declare that there is no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2019.04.008.

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