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Frailty and Technology: A Systematic Review of Gait Analysis in Those with Frailty

Michael Schwenk[a,b], **Carol Howe**[b,c], **Ahlam Saleh**[c], **Jane Mohler**[a,b], **Gurtej Grewal**[a], **David Armstrong**[a], and **Bijan Najafi**[a,b]

[a]Interdisciplinary Consortium on Advanced Motion Performance (iCAMP) and Southern Arizona Limb Salvage Alliance (SALSA), Department of Surgery, College of Medicine

[b]Arizona Center on Aging, University of Arizona, Tucson, Ariz., USA

[c]Arizona Health Sciences Library, University of Arizona, Tucson, Ariz., USA

Abstract

Background—New technologies for gait assessment areemerging and have provided new avenues for accurately measuring gait characteristics in home and clinic. However, potential meaningful clinical gait parameters beyond speed have received little attention in frailty research.

Objective—To study gait characteristics in different frailty status groups for identifying the most useful parameters and assessment protocols for frailty diagnosis.

Methods—We searched PubMed, Embase, PsycINFO, CINAHL, Web of Science, Cochrane Library, and Age Line. Articles were selected according to the following criteria: (1) *population:* individuals defined as frail, prefrail, or transitioning to frail, and (2) *outcome measures:* quantitative gait variables as obtained by biomechanical analysis. Effect sizes (d) were calculated for the ability of parameters to discriminate between different frailty status groups.

Results—Eleven publications met inclusion criteria. Frailty definitions, gait protocols and parameters were inconsistent, which made comparison of outcomes difficult. Effect sizes were calculated only for the three studies which compared at least two different frailty status groups. Gait speed shows the highest effect size to discriminate between frailty subgroups, in particular during habitual walking (d = 0.76–6.17). Gait variability also discriminates between different frailty status groups in particular during fast walking. Prominent parameters related to prefrailty are reduced cadence (d = 1.43) and increased step width variability (d = 0.64), whereas frailty (vs. prefrail status) is characterized by reduced step length during habitual walking (d = 1.32) and increased double support during fast walking (d = 0.78). Interestingly, one study suggested that dual-task walking speed can be used to predict prospective frailty development.

Conclusion—Gait characteristics in people with frailty are insufficiently analyzed in the literature and represent a major area for innovation. Despite the paucity of work, current results suggest that parameters beyond speed could be helpful in identifying different categories of frailty.

Conflict of Interest

The authors have no conflicts of interest to disclose.

Increased gait variability might reflect a multisystem reduction and may be useful in identifying frailty. In addition, a demanding task such as fast walking or adding a cognitive distractor might enhance the sensitivity and specificity of frailty risk prediction and classification, and is recommended for frailty assessment using gait analysis.

Keywords

Gait; Technology; Analysis; Assessment; Measurement; Frailty; Older adults

Introduction

The concept of ‘frailty’ is used to identify older adults at high risk of death, disability, and institutionalization [1, 2]. Frailty is characterized by low physiological reserves and vulnerability to illness and other stressors [1]. Based on recent estimates, 10% of community-dwelling older persons are frail and another 41.6% are prefrail, with increasing prevalence with age. Frail elders account for the highest healthcare costs in industrialized nations [3].

The five Cardiovascular Health Study (CHS) frailty index criteria (slow gait speed, low physical activity, unintentional weight loss, exhaustion, and muscle weakness [1]) are the most established for defining individuals as prefrail or frail. Among these criteria, gait speed has been reported as one of the strongest to predict adverse outcomes, such as mobility disability, falls, or hospitalization [4–6]. Despite this fact, gait analysis has not been used in routine assessment of frailty status. In particular, little is known about the association between gait parameters other than gait speed and categorical frailty status. Combining various spatiotemporal parameters of gait may enhance the sensitivity and specificity of frailty risk prediction and classification.

Advances in technology during the last decade have provided investigators and clinicians low-cost tools for measuring not only speed but other gait variables with high validity and practicability in research, clinical, and home settings [7, 8]. However, a precondition for the use of this technology for routine clinical assessment is a proper understanding of the relationship between gait parameters and frailty [9–12]. Acquiring more information about gait in older adults defined as frail has been repeatedly requested [9–11], and would enhance our understanding of ambulation patterns in this vulnerable population. Moreover, this information can serve as reference for follow-up studies.

The aim of the present review is to: (1) summarize current definitions, protocols, and technologies used for gait assessment in frail and prefrail populations, (2) study the relationship between categorical frailty status and gait characteristics, and (3) explore potential added value for using dual-task gait assessment for identification of frailty. The knowledge gained from this systematic review will inform clinicians about the potential application of gait assessment for prediction or evaluation of frailty status in their patients. It will also help inform researchers and engineers about the current shortcomings in the field and guide the development of different avenues for translating innovation in technology to routine clinical application relevant to frailty diagnosis and management.

Methods

Initial search terms were compiled and iteratively refined by content experts in the fields of library science, geriatrics, and gait and mobility. Articles were searched for in the following electronic databases: PubMed, Embase, PsycINFO, CINAHL, Web of Science, Cochrane Library, and Age Line. The following search strategy was used in the PubMed database: (‘Gait’[Mesh] OR ‘Gait Disorders, Neurologic’[Mesh] OR Walking [Mesh] OR Gait*[tw] OR walk*[tw] OR ‘dual task’[tw] OR ‘dual tasking’[tw] OR steptime[tw] OR step-length[tw] OR step[tw] OR stepping[tw] OR ‘single support’[tw] OR ‘double support’[tw] OR ‘double limb’[tw] OR stride*[tw] OR cadence*[tw] OR ‘swing time’[tw] OR ‘stance time’[tw] OR sway*[tw]) AND (‘Frail Elderly’[Mesh] OR frail*[tw] OR pre-frail [tw] OR pre-frailty [tw] OR prefrail*[tw]). Search strategies applied in the other databases were derived from the PubMed search. The database search was conducted without using language restrictions and limited to articles with publication dates up to 08/2012. Reference lists of relevant articles were subsequently hand-searched to identify additional papers.

Inclusion criteria were (1) *population:* individuals defined as frail, prefrail, or transitioning to frail by using a referenced definition, and (2) *type of outcome measures:* quantitative analysis of gait variables (e.g. speed, stride length, and variability) using biomechanical methods for assessment (e.g. electronic walkways, body-worn sensors, camera systems). Studies that only used a stopwatch for assessment were excluded.

Study selection was performed by two independent reviewers (M.S., C.H.). In case of disagreements, the articles were discussed with the other authors. Titles and abstracts of retrieved references were screened for inclusion and full texts of potential articles were further analyzed to determine if they met inclusion criteria. Case reports, letters, and systematic reviews were excluded. After inclusion, the study characteristics, research goals and mean findings with respect to gait were summarized. Articles were judged on methodological issues concerning complete description of population, frailty definition used, inclusion criteria, and protocols used for gait assessment. Spatiotemporal parameters were extracted from the studies in order to compare gait characteristics of individuals with different levels of frailty. For studies that reported gait variables for different frailty status groups (i.e. nonfrail, prefrail, frail), effect sizes (Cohen’s d [8]) were calculated for the ability of parameters to discriminate between these groups. Larger effect sizes suggest better discriminative validity.

Results

We found 2,012 articles through database searching. After removing duplicates and applying our inclusion criteria, 11 articles [9, 10, 12–20] remained for the analysis (fig. 1), including 8 (73%) cross-sectional studies [9, 10, 13–16, 18], 2 (18%) exercise trials [17, 19] and 1 (9%) longitudinal study [12]. Studies defined various research goals with respect to gait and frailty (table 1). In 55% (n = 6) of the studies [9, 13–15, 19, 20], older adults were classified as ‘transitioning to frailty’ based on the criteria of Speechley and Tinetti [21]. Three articles (27%) [10, 12, 18] used the established CHS frailty index [1], two of which [10, 18] subdivided individuals into groups of nonfrail, prefrail, and frail. One of them [10] used a modified CHS frailty index (without gait speed) and the Study of Osteoporotic Fractures Index [22] in addition to the CHS frailty index. Another study (9%) [17] defined frailty by using the physical performance test [23]. Finally, one of the selected studies (9%) [16] used a modified version of the physical performance test for defining frailty.

Sample sizes ranged from 16 to 631, and 3 studies divided their samples into subgroups according to frailty status [10, 16, 18]. Frailty subgroups were small, particularly for those subgroups with the highest degree of frailty (n = 13–20). Participants' mean age ranged from 72.2 to 83.6 years. Inclusion criteria differed between studies. Some authors only included individuals with a history of falls [9, 19, 20], whereas others specifically excluded fallers [13–15]. Several studies excluded individuals with cognitive impairment [9, 13–15, 18]. Some authors specified exclusion criteria such as depressive symptoms or major orthopedic diagnosis [9, 13–15, 19] whereas others only defined a physical performance test cut-off value <17 as exclusion criteria [16, 17].

Protocols Used for Gait Assessment

Table 2 summarizes the gait protocols used in the selected studies. The instruments most commonly used were electronic walkways (n = 3) [10, 12, 18], camera systems (n = 3) [9, 14, 15], or force plates (n = 3) [9, 19, 20]. Walking distance differed substantially across studies (range 4.3–20.0 m) and was not specified in some articles [16, 17]. Some authors measured steady-state walking [10, 12, 13], whereas others did not exclude acceleration and deceleration phases [14, 15], or did not specify these variables [9, 16–18]. Several studies [9, 10, 12, 16–19] did not specify if a walking aid was allowed during assessment. The number of walking trials ranged between 1 and 6 across studies and was not specified in one paper [18]. All gait tests were done during over-ground walking.

Gait Variables Reported

Some authors only reported a single parameter such as stride time [13] or speed [12], whereas others reported a number of variables [9, 10, 16–18] (table 2). The most frequently reported parameters were speed (n = 6) [9, 10, 12, 16–18], cadence (n = 5) [9, 10, 16–18] and stride length (n = 4) [9, 10, 16, 17]. Only two studies reported on gait variability by calculating the coefficient of variation [10, 13].

Gait Characteristics in Individuals with Different Frailty Statuses

Comparisons for Mean Parameters—Table 3 summarizes selected gait parameters in each frailty subgroup which were comparable between studies. Results suggest that transitionally frail individuals [9, 13] have reduced speed, cadence, stride length, and increased stride time, double support (as percentage of gait cycle), and stride time variability as compared to nonfrail individuals [10, 18]. Additionally, high variability between repeated walking trials (between-trials standard deviation) is evident and has been discussed as a specific sign of frailty onset [9]. Two studies [19, 20] reported that anticipatory postural adjustments during gait initiation were smaller and less forceful in transitionally frail elderly, as compared to healthy older adults as reported in the previous literature [24].

Effect sizes for discriminating between frailty status groups were estimated for three studies [10, 16, 18] and results are summarized in table 3. Estimated effect sizes varied across studies, gait parameters and protocol (habitual vs. fast walking). Out of two studies [10, 18] that compared gait parameters between nonfrail and prefrail, the effect size was significant only for the study of Montero- Odasso et al. [10], in particular for gait speed (d = 1.55 for habitual and d = 1.26 for fast-walking trial) and cadence (d = 1.43 for habitual and d = 0.81 for fast-walking trial). While comparing between nonfrail and frail groups, the effect size for both studies were significant, in particular for gait speed (d ≥ 2.46) and stride time (d ≥ 1.58). On the same note, effect size was significant for both studies for discriminating between prefrail and frail groups with more pronounced discrimination power for gait speed (d ≥ 0.76), step length (d = 1.32), and double support (d = 0.78).

Comparisons for Variability Parameters—Montero-Odasso et al. [10] compared gait variability between different frailty statuses. Specifically, the variability for stride time, stride length, step width, and double support were measured during both fast and habitual speed conditions. Among tested parameters during habitual speed, step width variability in the prefrail group was significantly increased compared to nonfrail persons (table 3). During the fast-walking condition, except for double support, all other gait variability parameters were significantly different between prefrail and nonfrail groups (table 3). None of tested parameters were significantly different between prefrail and frail groups. Interestingly, the authors reported that stride time variability under the fast-walking condition is the most prominent parameter associated with frailty stage in a multivariable linear regression model. Furthermore, by excluding speed criteria from frailty definition, they still found gait variability as a discriminator parameter for frailty stage identification.

Dual-Task Gait Assessment and Frailty

Two studies [13, 14] demonstrated that gait in individuals transitioning to frailty was more affected by dual arithmetic tasks (counting backwards) as compared to verbal fluency tasks (enumerating animal names). Whereas some gait characteristics were affected by both tasks (stride time, walking time, step number), others (stride time variability, lateral gait instability) were influenced by the arithmetic task only. Results suggest that an additional arithmetic task might be more sensitive to detect attention-related deficits during frailty onset, potentially due to a higher attentional load and/or more competitive interaction with executive functions [13, 14]. As a limitation, neither study compared dual-task-related gait changes of transitional frail older adults with nonfrail controls. Thus, it remains unclear which dual-task gait parameters are most responsive for identifying early signs of frailty.

Beauchet et al. [15] examined the relationship between intrinsic falls risk factors (age >85, polypharmacy, psychoactive drugs, poor vision, abnormal mobility, cognitive impairment) and dual-task-related gait changes in individuals transitioning to frailty. Dual-task-related gait changes were related to polypharmacy and impaired mobility, which were discussed as surrogate markers for multimorbidity. The authors concluded that with the cumulative damage of multimorbidity, walking requires more attentional resources in order to compensate for the decline in sensorimotor systems and cognitive processes. This in turn leads to higher dual-task gait deficits which may then be potential markers of frailty.

Verghese et al. [12] also explored gait characteristics under dual-task condition for prediction of frailty. Participants walked on an electronic walkway while reciting alternate letters of the alphabet. Additionally, single- task walking speed and functional performances (Short Physical Performance Battery [25]) were assessed. After 32 months' follow-up, 218 individuals out of 473 recruited nonfrail participants (46%) developed frailty. Dual-task speed was identified as a better predictor of prospective frailty development than the Short Physical Performance Battery (hazard ratios = 1.28 for dual-task speed version 1.19 for Short Physical Performance Battery).

Discussion

The small number of studies included in this review indicates that research on gait characteristics in individuals with confirmed frailty status is limited. A number of studies were excluded because they did not provide a definition of frailty. Others were excluded because they used a semi-objective approach for gait assessment (stopwatch), which does not provide spatiotemporal gait parameters beyond speed and is observer-dependent. The eleven included articles used different frailty definitions which limits comparison among these studies. For example, individuals defined as 'frail' by using the criteria of Reuben and Siu [23] had a higher walking speed (103 cm/s [17]) compared to individuals defined as 'frail' by the CHS criteria (80 cm/s) [10]. In addition, important confounders related to gait protocols which may influence outcomes such as walking distance [7], distance to achieve steady-state walking [26], and use of walking aids [27], were not controlled or were different across studies, indicating the lack of standardization of gait protocol for assessing frailty. Due to the limitations described above, we did not conduct a meta-analysis.

Which Gait Parameters May Be the Most Useful for Identifying Frailty?

Despite the methodological differences among reviewed research, this systematic review demonstrates that gait performance declines with progression of frailty as reflected by a number of spatiotemporal parameters. Gait speed showed high effect size for discriminating between frailty status groups, indicating that this parameter plays a key role for defining the level of frailty. These results are in line with a number of studies which have identified reduced gait speed as a predictor for adverse health events [4–6]. However, slow gait is a nonspecific variable, which is also linked to aging and other aging-related gait disorders. Assessment of gait speed does not, in and of itself, provide insight into the specific gait pattern, which in turn may limit the sensitivity and specificity of discrimination between different frailty statuses.

In this review we identified several gait parameters beyond speed, which may help to indicate the level of frailty. Estimating effect size from the reviewed studies suggests that reduced cadence has relatively high power to discriminate between nonfrail and prefrail and, thus, may be a sensitive parameter for early diagnosis of the frailty syndrome. On the other hand, progression of frailty (from prefrail to frail categorical status) may be strongly associated with reduced step length, while cadence is less affected. This may indicate that prefrailty is predominantly linked to deterioration in temporal parameters, whereas progression of frailty is linked with deterioration of spatial parameters of gait. Spatial parameters deterioration (e.g. reduced step length) may be due to declines in lower extremity strength and/or power as related to sarcopenia. Previous research has shown that reduced plantar flexor power is associated with reduced step length in healthy individuals [28]. Further studies may explore this potential association in frail individuals for identifying diagnostic and interventive approaches for maintaining spatial parameters such as appropriate training of plantar flexor muscles. Despite physiological changes, reduced spatial parameters are also characteristic of ‘cautious gait’ which is interpreted as an attempt to reduce the balance-control challenge during walking, for instance due to fear of falling [29].

In addition to mean gait parameters, gait variability parameters may also be indicators of specific frailty status [10]. Specifically, step width variability has been shown to be increased in prefrail compared to nonfrail individuals. Previous studies have also demonstrated the association between increased step width variability and impaired balance control and falls [30, 31], indicating the importance of this variable for assessing risk of falling in prefrail groups. Results of this review also highlight the potential benefit of gait initiation assessment for identifying early frailty, although no study has yet compared this specific phase of gait between differing frailty categories.

Interestingly, no association between age and gait performance has been reported in transitionally frail older adults [9], likely due to the wide heterogeneity of aged adults. In contrast, symptoms of frailty such as exhaustion and decreased physical activity are independently associated with reduced gait performance [10]. These findings support the idea that gait characteristics represent a cumulative measure of frailty and reflect a decline in multiple physiological systems indicating increased vulnerability to stressors, with associated adverse outcomes.

Which Gait Protocols May Be the Most Appropriate for Identification of Frailty?

The current standard for identification of frailty is assessing gait at habitual speed [1]. However, a self-selected pace may not sufficiently stress individuals with a lower physiological reserve. Results of this review indicate that future studies should also include a highly demanding task such as walking with maximum speed [10, 16] or adding a cognitive distractor [12–15], which may improve effect size and facilitate discrimination between frailty categories. The additional effort needed for fast-paced walking allows differences in function to emerge, and might thus be a more specific measure to identify increased vulnerability [10].

Notably, double support emerged as the parameter with the highest effect size to discriminate between prefrail and frail during fast walking. Increasing double support time is an attempt to minimize postural instability and indicates deficits in balance control [32]. It may be best detected under challenging walking conditions in people with frailty. On the same note, a frailty-related increase in stride time variability is better detected during fast walking [10]. Increased stride time variability may indicate disturbances of the automatic stepping mechanism due to impaired ability to adapt to physiologic stress (fast walking), indicating a frailty-related loss of complexity [10].

Not only a motor demanding task, but also a cognitively demanding task might be useful for stressing individuals, and be particularly sensitive in identifying those who are high functioning but who may be at risk of developing frailty [12]. Frailty-related dual-task deficits might be due to declines in sensorimotor systems [15] or subtly impaired cognitive functions, although cognitive impairment is a controversially discussed sign of the frailty phenotype [33]. Similar to single-task gait changes, dual- task gait changes were independent of age in individuals transitioning to frailty.

Future Research Direction

Currently, no clinimetrically sensitive technology exists for use within routine clinical care that would objectively quantify relevant gait parameters for indicating frailty status. Only one study included in this review used body-worn sensor technology for assessing gait [13], despite such technology representing a cost-effective and practical method for studying gait in both free-living environments such as the home or clinic, and the research environment. The use of body-worn sensors in frailty research may enable objective gait assessment for identifying frailty.

Only one study explored the predictive value of gait speed for prospective frailty status change. Future longitudinal studies are recommended to explore whether other gait parameters under differing conditions (e.g. dual task, fast walking, etc.) might enhance the power for prediction of prospective frailty development in older adults.

Furthermore, to date, only limited numbers of gait parameters have been compared across frailty categories, enabling better understanding of these categorical relationships. Some gait parameters may have a better association with frailty phenotype. For instance, stance time variability has been reported as useful in identifying older adults who are at risk for future disability development [34], and thus may be also associated with the frailty phenotype.

None of the reviewed studies addressed reliability of gait assessment for identification of frailty status. Thus, future studies should be conducted to explore whether gait variables are sufficiently reliable for frailty identification and sensitive to change over time. On the same note, new studies should address reliability of gait measurement in frail individuals under different gait conditions to standardize the protocol of gait assessment in frail people. For example, distance for assessing gait variability (6 m) might have been too short in existing studies [10], affecting reliability. Recent studies in older adults without confirmed frailty, suggest that at least 20 m distance [7] or at least 12 continuous steps [35] are required for a reliable measure of gait variability. If possible, gait assessment without a walking aid is recommended to better identify gait deficits [27]. If using gait accessories during gait measurement is required, results need to be adjusted to ensure a fair comparison between subjects. None of the reviewed studies reported any adverse events due to objective gait analysis in frail subjects, which suggests it is safely performed in this population.

Limitations

A meta-analysis was not conducted given the small number of studies and the limited standardization of methods. Thus, this paper does not provide reference values for frailty-related gait changes. However, we highlight specific gait parameters and protocols, which

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should be evaluated in future large-scale studies aiming to improve frailty screening, diagnosis, and management.

Conclusion

This review provides evidence that selected gait variables, beyond speed alone, are linked to specific stages of frailty. Both mean and variability gait parameters should be incorporated when assessing the frailty syndrome. Furthermore, it is recommended that gait be assessed during single task as well as under conditions that amplify individual physiological limits, such as fast-walking and dual-task conditions. Further studies are required to standardize the protocol of gait assessment in frail individuals as well as to identify the predictive value of gait assessment for prospective frailty development.

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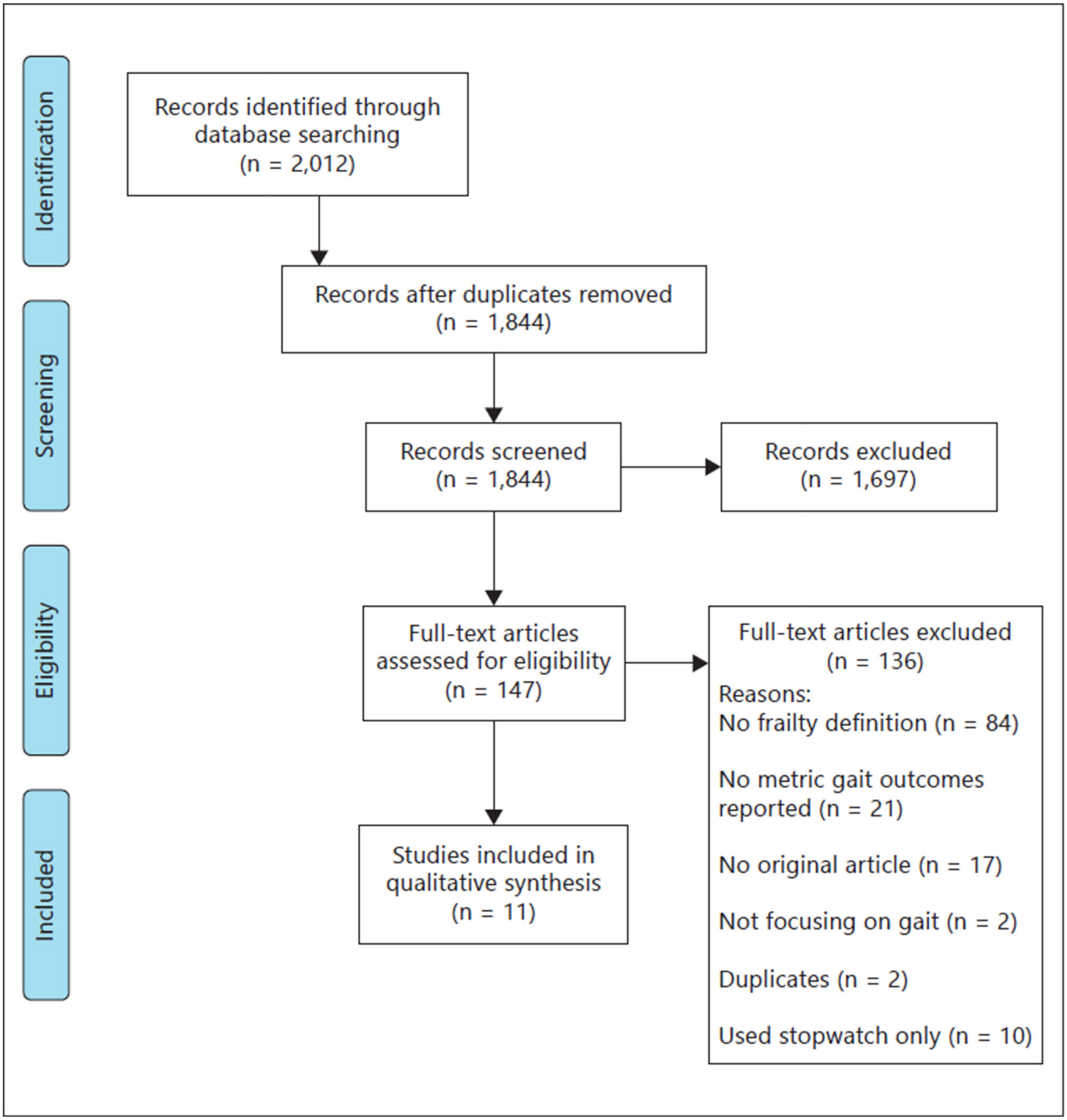

Fig. 1.
Flowchart of the process of literature search and extraction of studies meeting the inclusion criteria.

Table 1

Study characteristics, research aims, and mean findings with respect to gait for the studies included in the systematic review

Reference	Main aim of the study with respect to gait	Frailty definition	Subjects	Age, mean (% female)	Mean findings with respect to gait
Cross-sectional studies					
Kressig [9]	Examining gait characteristics in transitionally frail older adults and compare with older populations	Speechley and Tinetti [21]	Transitional frail: n = 50	79.6 (90%)	Speed, stride length, and cadence were lower in transitional frail adults compared to healthy elderly, higher compared to fearful fallers, and similar compared to vigorous elderly
Montero-Odasso [10]	To assess whether gait variability is associated with frailty	Fried et al. [1]; Ensrud et al. [22]	Frail: n = 20 Prefrail: n = 55 Nonfrail: n = 25	Total sample: 82.2 (78%) Non-frail: 81.0 Pre-frail: 83.0 Frail: 82.0	Stride time variability under fast gait condition was the most prominent parameter consistently associated with frailty
Beauchet [13]	Compare the effects of two different cognitive tasks on gait	Speechley and Tinetti [21]	Transitional frail: n = 16	72.2 (75%)	Mean stride time increased under both dual-task conditions CV increased only with arithmetic task
Beauchet [14]	Compare the effects of two different cognitive tasks on gait	Speechley and Tinetti [21]	Transitional frail: n = 30	82.6 (90%)	Walking time and number of steps increased under both dual-task conditions Lateral gait instability increased only with arithmetic task
Beauchet [15]	Study the relationship between intrinsic falls risk factors and dual-task-related gait changes	Speechley and Tinetti [21]	Transitional frail: n = 66	83.6 (85%)	Walking time and number of steps increased under dual-task conditions Polymedication and abnormal mobility were associated with dual-task deficits
Brown [16]	Examine the relationship of multiple physical factors (gait amongst others) with the PPT	Reuben and Siu [23]; Guralnik et al. [25]	Nonfrail: n = 39 Mildly frail: n = 48 Moderately frail: n = 20	Total sample: 83.0 (75%) Subsamples: n/a	All gait parameters were significantly related to PPT score (r = 0.375–0.528) Only fast-gait speed discriminated between the three frailty groups
Da Silva [18]	To determine differences in functionality and gait between fallers and nonfallers in frailty groups	Fried et al. [1]	Nonfrail: n = 51 Prefrail: n = 61 Frail: n = 13	Total sample: 73.8 (70%) Subsamples: n/a	Gait parameters discriminated prefrail from frail and nonfrail from frail Gait did not differ between fallers and nonfallers in different frailty status groups
Hass [20]	Examine differences in COP trajectories during gait initiation	Speechley and Tinetti [21]	Transitional Frail: n = 28 PD: n = 16	Transitional frail: 80.2 (n/a) PD: 66.6 (n/a)	Transitional frail older adults had more coordinated COP movements compared to PD
Longitudinal studies/exercise trials					
Verghese [12]	To examine the validity of a WWT to predict frailty, disability, and death	Fried 2001 [1]	Overall: n = 631 Follow up:	Overall: 79.9 (61%) Follow-up: 80.2 (66%)	WWT better predicted frailty compared to SPPB

Reference	Main aim of the study with respect to gait	Frailty definition	Subjects	Age, mean (% female)	Mean findings with respect to gait
			Frail: n = 218		
Brown [17]	To examine the effects of a low-intensity exercise program on physical frailty	Reuben and Siu [23]	Frail: n= 87 (IG: n = 48; CG: n = 39)	IG: 83 (58%) CG: 83 (56%)	Only cadence during usual speed walking was improved in the IG compared to CG
Hass [19]	To determine if a Tai Chi program as compared to a wellness education improves gait initiation	Speechley and Tinetti [21]	Transitional frail: n = 28 (IG: n = 14; CG: n = 14)	IG: 79.5 (n/a) CG: 79.7 (n/a)	Tai Chi improved the mechanism by which forward momentum is generated and improved coordination during gait initiation

CV = Coefficient of variation; PPT = physical performance test; COP = center of pressure; PD = Parkinson’s disease; WWT = walking while talking test; SPPB = short physical performance battery; IG = intervention group; CG = control group.

Table 2

Methods of gait assessment and gait parameters reported in studies

	Reference										
	Kressig [9]	**Montero-Odasso [10]**	**Verghese [12]**	**Beauchet [13]**	**Beauchet [14]**	**Beauchet [15]**	**Brown [16]**	**Brown [17]**	**Da Silva [18]**	**Hass [19]**	**Hass [20]**
Methods of gait assessment											
Instrument	camera, force platform	walkway	walkway	BWS	camera	camera	foot switches	foot switches	walkway	force platform	force platform
Distance, m	8	6	4.6/6.1	20	10	10	n/a	n/a	4.3	gait initiation	gait initiation
Steady state	n/a	steady state	steady state	steady state	accel./decel.	accel./decel.	n/a	n/a	n/a	accel.	accel.
Number of trials (speed)	6 (usual)	3 (usual) 3 (fast)	1 ST 1 DT[a] (usual)	1 ST 2 DT[b, c] (usual)	1 ST 2 DT[b, c] (usual)	1 ST 1 DT[b] (usual)	2 (usual) n/a (fast)	2 (usual) 2 (fast)	n/a	3 left leg 3 right leg (usual)	6 forward 6 lateral (n/a)
Walking aid allowed	n/a	n/a	n/a	no	no	no	n/a	n/a	n/a	n/a	no
Gait parameters reported											
Speed	M	M	M	–	–	–	M	M	M	–	–
Cadence	M	M	–	–	–	–	M	M	M	–	–
Stride length	M	M, CV	–	–	–	–	M	M	–	–	–
Stride time	–	M, CV	–	M, CV	–	–	–	–	–	–	–
Step length	–	–	–	–	–	–	–	–	M	–	–
Step time	–	–	–	–	–	–	–	–	M	–	–
Step width	–	M, CV	–	–	–	–	–	–	–	–	–
Double support	M	M, CV	–	–	–	–	–	–	M	–	–
Single support	–	–	–	–	–	–	–	–	M	–	–
Stance	M	–	–	–	–	–	M	M	–	–	–
Swing	M	–	–	–	–	–	–	M	–	–	–

	Reference										
	Kressig [9]	**Montero-Odasso [10]**	**Verghese [12]**	**Beauchet [13]**	**Beauchet [14]**	**Beauchet [15]**	**Brown [16]**	**Brown [17]**	**Da Silva [18]**	**Hass [19]**	**Hass [20]**
Double stance	–	–	–	–	–	–	M	M	–	–	–
Support base	–	–	–	–	–	–	–	–	M	–	–
Walking time	–	–	–	–	M	M	–	–	–	–	–
Step number	–	–	–	M	M[d]	M	–	–	–	–	–
Heel speed	M			–	–	–					–
COP trace	–	–	–	–	–	–	–	–	–	M	M

ST = Single task; DT = dual task; M = mean; CV = coefficient of variation; COP = center of pressure; BWS = body-worn sensor.

[a]Reciting alternate letters of the alphabet.

[b]Counting backwards.

[c]Enumerating animal names.

[d]Number of steps and number of lateral line stepping.

Table 3

Gait parameters in different frailty status groups

Reference	Frailty status group (compared groups)	Speed, cm/s	Cadence, steps/min	Stride length, cm	Step length, cm	Stride time, s	Double support, % GC	Swing, % GC	Stance, % GC	Stride length var., CV	Step width var., CV	Stride time var., CV	Double support var., CV
Studies used the frailty criteria of Speechley and Tinetti [21]													
Kressig [9]	Transitionally frail[a]	97±23	106±13	111±18	–	–	32±6	34±3	66±3	–	–	–	–
Beauchet [13]	Transitionally frail[a]	–	–	–	–	1.1±0.1	–	–	–	–	–	3.6±1.8	–
Studies used the CHS frailty index [1]													
Montero-Odasso [10]	Nonfrail[a]	124±13	118±6	127±14	64±6[e]	1.0±0.1	28±3	–	–	4.0±1.5	5.0±1.5	2.3±1.1	9.5±4.8
	Prefrail[a]	95±21	106±9	109±18	56±8[e]	1.1±0.1	32±5			5.1±2.8	6.6±2.9	3.0±1.4	8.8±3.3
	Frail[a]	80±19	101±21	99±16	51±8[e]	1.2±0.1	34±5			5.7±2.2	6.7±1.7	3.8±2.0	10±4.8
	Non vs. Pre: d, sig	1.55*	1.43*	1.05*	1.08*	1.22*	0.80*			n.s.	0.64*	n.s.	n.s.
	Non vs. Frail: d, sig	2.77*	1.15*	1.87*	1.86*	1.88*	1.51*			n.s.	1.09*	0.95*	n.s.
	Pre vs. Frail: d, sig	0.77*	n.s.	n.s.	0.68*	0.60*	n.s.			n.s.	n.s.	n.s.	n.s.
	Nonfrail[b]	155±19	133±9	140±16	71±8[e]	0.9±0.1	26±3	–	–	2.9±0.8	4.1±1.0	1.8±0.7	7.8±3.1
	Prefrail[b]	125±26	122±15	122±21	62±10[e]	1.0±0.1	28±5			4.1±2.0	5.7±2.5	2.6±1.0	9.3±6.0
	Frail[b]	106±22	109±22	107±24	54±11[e]	1.0±0.1	32±6			4.5±1.7	5.8±1.8	2.9±1.7	9.8±4.5
	Non vs. Pre: d, sig	1.26*	0.81*	0.96*	0.93*	0.77*	n.s.			0.68*	0.74*	0.88*	n.s.
	Non vs. Frail: d, sig	2.46*	1.44*	1.69*	1.68*	1.58*	1.41*			1.18*	1.27*	0.90*	n.s.
	Pre vs. Frail: d, sig	0.76*	0.76*	0.69*	0.66*	0.59*	0.78*			n.s.	n.s.	n.s.	n.s.
Verghese [12]	Will develop frailty[a, c]	96±16	–	–	–	–	–	–	–	–	–	–	–
Da Silva [18]	Nonfrail[d]	116±5	112±12	–	62±8	–	39±2	–	–	–	–	–	–
	Prefrail[d]	111±5	110±13		60±9		39±2						
	Frail[d]	79±9	99±12		48±9		38±3						
	Non vs. Pre: d, sig	n.s.	n.s.		n.s.		n.s.						

Reference	Frailty status group (compared groups)	Speed, cm/s	Cadence, steps/min	Stride length, cm	Step length, cm	Stride time, s	Double support, % GC	Swing, % GC	Stance, % GC	Stride length var., CV	Step width var., CV	Stride time var., CV	Double support var., CV
	Non vs. Frail: d, sig	6.17*	1.13*		1.58*		n.s.						
	Pre vs. Frail: d, sig	5.70*	0.9*		1.32*		n.s.						
Studies used the frailty criteria of Reuben and Siu [23]													
Brown [16]	Nonfrail[b]	157±37	n.r.	n.r.	–	–	n.r.	n.r.	n.r.	–	–	–	–
	Mildly frail[b]	136±31	n.r.	n.r.			n.r.	n.r.	n.r.				
	Moderately frail[b]	101±30	n.r.	n.r.			n.r.	n.r.	n.r.				
	Non vs. Mild: d, sig	0.63*	n.r.	n.r.			n.r.	n.r.	n.r.				
	Non vs. Mod: d, sig	1.63*	n.r.	n.r.			n.r.	n.r.	n.r.				
	Mild vs. Mod: d, sig	1.14*	n.r.	n.r.			n.r.	n.r.	n.r.				
Brown [17]	Frail[a]	103±21	108±11	106±18	–	–	–	32±2	68±2	–	–	–	–

Given are the results of gait analysis according to frailty status group as reported in the papers included. Decimals were rounded to improve the readability of the table. var. = Variability; GC = gait cycle; CV = coefficient of variation; Mod = moderate; sig = significant; n.r. = gait parameter measured but value not reported; – = gait parameter not measured; n.s. = not significant;

*significant differences between frailty subgroups ($p \leq 0.05$); d = effect size (Cohen's d) for discriminating between different frailty status groups. Effect sizes have been calculated based on the original values as stated in the papers.

[a]Assessment with usual walking pace.

[b]Assessment with fast walking pace.

[c]Values for older adults who will develop frailty within the next 32 months.

[d]Average values of the fallers and nonfallers group.

[e]Step width as calculated as the distance from the midpoint of the footstep in front to the midline midpoint of the trailing footstep on the opposite foot.