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TITLE

Are the Spatio-temporal Parameters of Gait Capable of Distinguishing a Faller from a Non-faller Elderly?

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Conflicts of interest

The authors have declared that no competing interests exist.

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Abstract

Background: Fall is a common and a major cause of injuries. It is important to find elderlies who are prone to falls. The majority of serious falls occur during walking among the older adults. Analyzing the spatio-temporal parameters of walking is an easy way of assessment in the clinical setting, but is it capable of distinguishing a faller from a non-faller elderly?

Aim: The objective of this systematic review was to identify and summarize the differences in the spatio-temporal parameters of walking in elderly fallers and non-fallers and to find out if these parameters are capable of distinguishing a faller from a non-faller.

Design: Systematic review of the literature.

Setting: NA

Population: NA

Methods: All original research articles which compared any special or temporal walking parameters in faller and non-faller elderlies were systematically searched within the Scopus and Embase databases. Effect size analysis was also done to standardize findings and compare the gait parameters of fallers and non-fallers across the selected studies.

Results: The electronic search led to 5381 articles. After title and abstract screening 30 articles were chosen; further assessment of the full texts led to 17 eligible articles for inclusion in the review. It seems that temporal measurements are more sensitive to the detection of risk of fall in elderly people. The results of the 17 selected studies showed that fallers have a tendency toward a slower walking speed and cadence, longer stride time, and double support duration. Also, fallers showed shorter stride and step length, wider step width and more variability in spatio-temporal parameters of gait.

Conclusion: According to the effect size analysis, step length, gait speed, stride length and stance time variability were respectively more capable of differentiating faller from non-faller elderlies.

However, because of the difference of methodology and number of studies which investigated each parameter, these results are prone to imprecision.

Clinical Rehabilitation Impact: Spatio-temporal analysis of level walking is not sufficient and cannot act as a reliable predictor of falls in elderly individuals.

Key words: falls, faller, aged, elderly, walking, cadence, step width, step length, gait variability.

Introduction

Why are falls an issue?

One third of people 65 years or older fall each year and half of them experience recurrent falls (1, 2). Sixty percent of people who die as the result of a fall are within this age bracket (3). According to the injury costs associated with treating the elderly in western society, which includes the USA, Australia, the EU and the United Kingdom, falls are the major cause of injuries and a significant source of economic burden that account for somewhere between 0.85% and 1.5% of national health care expenditure (4). Eighty seven percent of fractures in the elderly are the consequence of a fall (3) and over 90% of hip fractures are associated with falls (5-7). Other fall-induced injuries include head injuries, joint dislocation/sprain and soft tissue injuries (2, 8, 9).

Who is an elderly faller and what are falls?

A fall could be defined as a situation in which the individual comes to rest at a lower level (e.g. floor, furniture) accidentally or unintentionally (10). A number of existing studies that examine falls have been more specific in the criteria used to define a fall (11-15). More specifically, in order to exclude falls that can be attributed to a particular reason, falls can be categorized as either explained (e.g. as a result of a trip or slip or a syncope or vertigo) or unidentified (i.e. the reason for the fall cannot be readily explained). Falls are multifactorial and they can happen as the result of both intrinsic and extrinsic factors (16). Intrinsic factors are related to the person him/herself, impairments in functions that may disturb postural control ability, impaired cognition and visual impairment. Extrinsic factors include environmental hazards (poor lighting, slippery floors and uneven surfaces, etc.), footwear and medications/side effects (16-20).

Different studies have employed different criteria to identify a person as a faller. In the majority of existing studies fallers were defined as elderly people who have experienced at least one fall during the previous one year (11, 12, 21-24); however, in alternative studies, this criteria ranged from two falls in four months (25) to one fall in five years (26). Thus, in some studies, fallers were further categorized as recurrent or one-time fallers, with recurrent fallers being those that have experienced falls twice or more during a defined period of time (16).

Lord et. al found that visual contrast sensitivity, proprioception in the lower limb, quadriceps strength, reaction time and sway on foam rubber surface are the factors that can significantly differentiate recurrent fallers from one-time fallers and non-fallers; however, these factors were similar between one-time fallers and non-fallers (27). Moreover, research has shown that frequent fallers have a slower and more variable gait (cadence, swing time) than non-fallers and one-time fallers, which could be related to the lower quadriceps strength of these individuals (26, 28). On the other hand, Gunter et al. found no difference between functional mobility and lower extremity power and strength between one-time and frequent fallers (12). Kosik et al. demonstrated that one-time fallers are more prone to major injuries than recurrent fallers (29).

Falls can also be divided as injurious and non-injurious or as causing major, minor or moderate injuries. An injurious fall or a fall with serious or major injury can be defined as a fall that leads to fractures, joint dislocation, or soft-tissue injuries that require medical attention (16, 29-31).

What activities can mostly lead to a fall?

As reported by Talbot (32), across all age groups and among different activities that were performed just before serious falls, the majority of serious falls occur during ambulation and this mostly involves running in younger adults and walking for the older group (mean age 76.2). In older people, most falls occur indoors. In the elderly, the most frequent perceived cause of fall pertains to balance and gait imbalance. In another study by Nino, it was reported that most falls occur during walking and in daytime outdoor activities (33).

Depending on the functional ability of the elderly, the activities associated with falls can vary. For example, one study demonstrated that injurious falls involving independent elderly people mostly occur while such individuals are engaged in running and jumping activities and less serious injuries may occur if an individual falls while walking; however, for elderly with low functional ability, no activity is related to a high risk of injurious falls (34).

Aim

As mentioned above, walking is the activity that is most commonly associated with falls. As such, the purpose of this review was to identify spatio-temporal differences in the gait parameters and patterns in elderly fallers and non-fallers. Moreover, the research aimed to establish whether these parameters were capable of distinguishing a faller from a non-faller.

Method

Search Strategy

All original research articles published between 1980 and August 2012 were systematically searched within the Scopus and Embase databases.

The following keywords were used to locate relevant articles:

- gait OR locomotion OR walk OR
- AND faller OR falls OR falling OR
- AND age OR aging OR geriatric OR old OR older

After the initial search, the researchers decided to exclude studies that pertained to neurological diseases (Parkinsons and multiple sclerosis) and children. Hence, the keywords were limited as below:

AND NOT

- parkinson
- multiple sclerosis
- parkinsonian
- child

In the Scopus, the keywords were searched in the article title, abstracts and keywords and the subject areas were limited to life sciences, health sciences and physical sciences. In the Embase database, each of the above set of keywords was first searched separately before being combined. The search results were further confined as presented in Appendix A.

The results were reviewed by two independent reviewers (NM, MM). First, the articles where selected according to their titles and then their abstracts. The selected studies by the two reviewers were compared and any inconsistencies were discussed before the final papers were selected for the full text review. Finally, some potential references were reviewed by full text. Articles that addressed the specifications mentioned in Table 1 were included. Studies that were solely about dual task and studies that used only functional tests and reported those scores were excluded. In addition to this, the references of the selected articles were evaluated for related titles that were published between 1980 and 2012.

Data analysis

In this literature review the effect size (ES) was also calculated for different variables to standardize findings across studies so that differences in the gait parameters of fallers and non-fallers could be directly compared. One of the important issues relating to the effect size concerned its independence from the sample size. Cohen's d as a measure of ES was calculated using the following equation (35, 36):

In the above equation, X_F represents the mean for the faller group, X_{NF} represents the mean for the non-faller group and S_{pooled} is the pooled standard deviation of the faller and non-faller groups. As suggested by Cohen, the values of 0.2, 0.5 and 0.8 are considered to be small, medium and large values for d. Effect size can be interpreted as the percentile of the non-overlap of the distribution of the faller group and non-faller group. For example, an ES of 0.0 means a complete overlap of the two groups, and an ES of 0.8 indicates 47.4% of non-overlap between fallers and non-fallers. (35)

Results

Study Characteristics

The electronic search produced 5384 results. Search results from the two databases were imported to separate EndNote (Version X5, Thomson, Reuters). Using the EndNote software, duplications were found and 1248 articles were consequently excluded. After screening the articles through the title and abstract, 30 articles were chosen for further assessment. After the final screening of the full text, 13 articles were considered eligible for inclusion in the review and, among the references of the selected articles, four more articles were identified as being eligible (Figure 1). Articles were excluded for common reasons, including the following:

- The gait analysis was only focused on the kinetics
- The research focused on the risk of fall while performing a dual task
- Trip or slip related falls were studied
- The research was limited to the use of functional tests and gait scoring to compare walking of fallers vs. non-fallers
- The studies did not involve elderly fallers who had a history of previous falls, or they were prospective studies.

One study was excluded because no information was provided about the age of the participants (37). All studies were case-control studies, with the exception of three, which were cross-sectional studies (11, 38, 39).

Prospective studies were excluded because usually higher rate of falls are reported in them compared to retrospective studies. That is, in retrospective studies as a result of low accuracy in remembering the incidences after a long duration such as 12 months less falls are reported subjectively (40). To have a more consistent pool of data, the prospective studies were eliminated.

Participants

All of the studies involved subjects who were elderly fallers and non-fallers. Two studies concentrated only on female subjects (15, 22), and two studies did not give any information about the number of male and female participants (23, 24). In some of the studies, elderly people were defined as people who were aged above 60 (11, 15, 24, 38). The mean age of the elderly participants involved in the studies was 77.4. The majority of the selected studies defined a faller as someone who has experienced at least one fall during the preceding year (11, 22-24, 38, 39). This definition ranged from two falls in four months (25) to one fall in five years (26). Some of the studies considered the environment and cause of the fall in the definition of the fall. For example, falls that were the result of a specific disorder, active orthopedic condition, unavoidable environmental hazards or during sports activities, were not accepted (11, 13-15, 41).

Both faller and non-faller groups were healthy older adults. Most of the studies involved older individuals who were free of orthopedic and neurological impairments, were living in the wider community, and were able to walk unassisted for the duration of the tests. More details about the participants of the studies are presented in Table 2.

Devices and methods of measurement

Different devices and methods were used in the selected studies to measure the spatio-temporal parameters of gait. The most common method involved the use of an infrared camera motion analysis system with force platform (13-15, 24, 41, 42). The second most commonly employed measurement devices were instrumented gait measurement systems such as GaitMat®, GaitRit® (11, 38, 39, 43). Two studies used accelerometers to measure gait parameters such as speed, stride frequency and symmetry (21, 44). One study utilized length-voltage transducer by means of threads to measure longitudinal displacement of walking and gait parameters such as step length, duration of single and double support phase (23). Eke-Okoro measured the speed of walking using a stopwatch (25). Hausdorff et al. used foot switches (26) and Gehlsen et al. filmed elderly fallers and non-fallers as they walked on a treadmill (45). Finally, in 1989, Heitmann used footprints on a paper walkway. A brief explanation of the devices and methods used in each study is presented in Table 3.

Within all the tests the subjects walked in a straight line on a level walkway. The walking speed in most of the studies was at a self-selected or normal walking speed. In almost one third of the studies walking was analyzed at different speeds (fast to slow) (13, 24, 25, 41, 44). In only one study the treadmill was used, and walking was performed at two different speeds (45).

Measured variables

In all of the selected studies at least one spatio-temporal parameter of gait was measured and compared between fallers and non-fallers, or included an analysis of the relationship that a previous fall could have with the spatio-temporal parameters of gait. Temporal variables such as cadence, single and double support duration, step and stride time and walking speed; and spatial variables such as, stride and step length, step width were incorporated.

Other complex variables were also measured, including gait variability, stride regularity and symmetry, center of mass and center of pressure inclinations angles in sagittal and frontal planes. In one study the kinematic parameters of gait, such as peak range of motion in the lower limb joints, were measured.

Apart from the main spatio-temporal parameters, in the selected 17 studies, other variables including one-leg balance test (15, 22, 43), torque and power measurements of the lower extremity (14, 41), and other functional gait and balance tests were also implemented. Table 3 presents the information pertaining to the spatio-temporal gait measurements.

Figure 2 presents the calculated effect sizes.

Temporal Gait Parameters

Cadence

In six studies cadence was compared between fallers and non-fallers (13, 15, 24, 38, 39). In a study by Shimada, a significant relationship was found between a history of fall and cadence (OR= 1.06, CI: 1.02 - 1.10, p<0.01). That is, there is a greater risk of falling for elderlies with faster cadence and the combination of short stride and slow cadence also increases the risk of fall (39). Furthermore, Newstead found a significant faster cadence among non-fallers compared to fallers at both fast and comfortable speeds of walking (24).

However, two alternative studies found that there was no significant difference in the cadence of fallers and non-fallers (15, 38), and in two studies by Kerrigan and Lee L.W., the normal walking speed cadence of fallers was 77% and 89% of the cadence of non-fallers, respectively. The effect sizes for these two studies were also high (ES: 1.4 and 0.8).(13, 14) at the fast walking speed; this amount increased to 99% of cadence of non-fallers in the Kerrigan's study.

Stride Time

In three studies the stride length of elderly fallers and non-fallers was compared (15, 26, 45). In the Toulott and Gehlsen's study no difference was found between the stride time of fallers and non-fallers (15, 45). However, Hausdroff studied the stride time variability of elderly fallers and non-fallers and he found that the stride time was significantly greater in fallers (ES=1.1). Moreover, fallers showed higher stride time variability both in terms of standard deviation (absolute magnitude of variability) and coefficient of variance (CV: variability normalized to mean value). Variability in stride time was almost the same for one-time and recurrent fallers (CV: 4.2±1.1% and 4.1±1.3%

respectively). People who had experienced fall(s) more than one year previous showed less stride time variability (CV:3.9±1.2%) than people who had experienced fall(s) in less than a year (CV: 4.2±1.1). He also found that stride variability is independently associated with fall status after controlling for the potentially confounding effect of age, weight, height, gender, and medication use.

Duration of Single and Double Support

In six studies the difference between single and double support duration between fallers and non-fallers was compared (15, 23, 24, 38, 43, 45). Mbourou, Nelson and Newstead found that fallers spend greater time in double support than the non-fallers at a comfortable walking speed. However, Nelson found no difference between fast and slow walking speeds. Moreover, in two alternative studies no difference was found between the double support duration in fallers and non-fallers (38, 45). Toulott and Gehlse and Da Silva found that the single support durations in normal walking speed and in two speeds on the treadmill (4 and 6 km/h) was not different between the two groups (15, 38, 45).

Walking Speed

Twelve studies examined the impact of the speed of walking on fallers and non-fallers (11, 14, 15, 21, 24, 25, 38, 39, 41-44). In eight of them, the velocity of normal or comfortable walking was significantly lower in fallers compared to non-fallers and the ES ranged from 0.7 to 16.1(14, 21, 24, 39, 41-44). In three studies (11, 15, 38) no statistically significant difference was found between the two groups. However, in almost all of the studies the walking speed was greater in non-fallers.

In one study a significant relationship was found between the history of fall and gait speed (39). In four studies the spatio-temporal parameters of gait were also measured at both fast and slow speeds of walking in addition to comfortable or self-selected speeds (13, 24, 25, 41, 44). Kojima and Newstead found that, at the fast walking speed, fallers walked at a significantly slower walking speed than non-fallers (ES: 0.7 and 1.2, respectively).

Spatial Gait Parameters

Stride length

In ten studies the stride length was compared between fallers and non-fallers (15, 21, 23-25, 38, 39, 41, 42). In five studies fallers showed significant reduction in stride length compared to non-fallers (21, 23, 24, 41, 42). In Newstead's study, the stride length of fallers was significantly shorter than non-fallers, but at a slow walking speed this difference was not observed (24). Mbourou found the main effect of group (faller and non-faller elderly) for step length. He found that fallers' first stride (first after the after the initial step) was significantly shorter than the second stride, which was not the case for non-fallers. Moreover, variability in the faller's first and second stride (CV: 27.6% and 21.5%, respectively for the first and second stride) was much greater than that of the non-fallers (CV: 3.7% and 3.05%, respectively) (23). Kirregan compared the stride length of fast walking of fallers with comfortable walking of non-fallers. The results showed that the stride length of fallers in fast walking was slightly less than the non-fallers' stride length while walking at a comfortable speed (41).

On the contrary, Da Silva, Toloutt and Gehlsen found no difference in the stride length of fallers vs. non-fallers in the single task of walking, but Toulett found a significant difference between these groups when they were performing the dual-task test (15, 38, 45). Moreover, Shimada found that stride length alone is not associated with a fall, but when a short stride is combined with a slow cadence it can significantly increase the risk of fall (39). Gehlsen found no significant difference between the two groups while walking at two gait speeds on a treadmill (4 and 6 km/h). He also compared the normalized stride length (with the subject's height and leg length) and found no significant difference.

Step length

In five studies the step length was compared between the fallers and non-fallers (11, 14, 15, 23, 24, 45). In all of them the fallers had a shorter step length; however, this difference only proved significant in three of them (23, 24, 42).

Newstead found that the changes in step length were different in the two groups at different speeds of gait (significant group by condition interaction for step length). Moreover, step length was significantly shorter for fallers during comfortable walking and obstacle clearance (24).

Step Width

In five studies, step width was compared between fallers and non-fallers (11, 22, 39, 42, 45). In three of them the step width of fallers was increased when compared with non-fallers (in the Lee et al. and Gehlsen et al. studies the ES was as big as 0.7), but only in one of them (45), this difference was statistically significant (22, 42, 45). Gehlsen found that during fast walking on the treadmill (6km/h), the fallers heel width was significantly greater than that of the non-fallers ($p<0.05$), but at the slower speed (4km/h) this difference was not significant (45). Shimada also found no significant relationship between fall history and step width.

Gait variability

In five studies the variability of walking was compared between fallers and non-fallers. Hausdorff et al. measured temporal variability, Mbourou and Heitmann measured spatial variability, and finally Brach studied them both. In these four studies variability was calculated as the coefficient of variance, which is percentage of standard deviation divided by mean. For the temporal variability, Hausdorff found that stance, swing and stride time variability were significantly higher for fallers than they were for non-fallers, yet, according to Brach, step and stance time variability were not different between the two groups (22, 23, 26).

For the spatial variability, the results of Brach's study were again different; that is, Brach did not find any difference between fallers and non-fallers in step length but Mbourou found both step and stride length variability to be higher in the fallers. Mbourou also found that not only did fallers have a significantly shorter first step than non-fallers, but also that their first step variability was almost twice that of non-fallers.

Brach and Heitmann studied the difference of step width variability in the fallers and non-fallers. In both studies, fallers showed more step width variability than non-fallers; however, this difference was not statistically significant. Brach divided the subjects into fast and slow walkers (≥1.0 m/s or <1.0 m/s). In subjects with a normal walking speed of ≥1.0 m/s, the step width variability of fallers was significantly greater than that of non-fallers (ES=0.4), which was not the case for the slow walkers (ES=0.0).

Brach also divided the subjects into people with extreme variability (extremely high or low) in step width and he found that the people with extreme step width variability were more prone to falling than people with moderate variability (11, 22, 23).

Auvinet et al. used a different method to analyze variability. He utilized two accelerometers (Locometrix ™ gait analysis system) to measure the stride symmetry and regularity in fallers and non-fallers. He found that these variables were significantly less in fallers than they were in non-fallers, but only stride regularity could be a predictor of fall in elderly people because, as reported previously in another study by Auvinet, the stride symmetry could be mainly due to an existing pathology, such as osteoarthritis or a neurological complication (46).

Discussion

Most falls happen during walking and analyzing the temporal and spatial parameters of walking is a relatively easy task that can be performed in a clinical setting. Hence, in this literature review all the studies that measured and compared these two aspects of walking in elderly faller and non-fallers have been reviewed. The purpose of this study was to understand the spatio-temporal differences of walking between healthy elderly fallers and non-fallers and to establish the extent to which these differences are dependable in discriminating between elderly fallers and non-fallers. Through the comprehensive review of all 17 selected articles the following parameters were the most measured and reported: temporal parameters, including cadence, stride time, duration of single and double support, and walking speed; spatial parameters, including stride and step length, and step width.

Around 50% of the studies that measured temporal variables found some difference between fallers and non-fallers and among those that measured spatial variables, about 40% found significant differences. So it could be argued that temporal measurements are more sensitive to the detection of risk of fall in elderly people.

The results of the 17 reviewed studies showed that fallers have a tendency toward a slower walking speed and cadence, longer stride time, and double support duration. Moreover, fallers showed shorter stride and step length, wider step width and more variability in spatiotemporal parameters of gait (47). One of the major changes of walking in the elderly concerns speed reduction. As reported in a meta-analysis of 41 studies published before 2009, for the community-living men and women, the self-selected walking speed was 1.25m/s for the age group 60-69, 1.17m/s for age group 70-79, and 0.95m/s for elderlies aged 80-99 years old. The normal and functional walking speed range is 1.20-1.40 m/s (48). Shimada found that self-selected walking speed is the best test for evaluating fragility in elderlies. He also explained that a self-selected walking speed lower than 0.7 m/s could be a predictor of future falls (49). The elderly fallers of the 10 studies included in this review showed a mean comfortable walking speed of 0.87±0.20. The mean self-selected walking speed of non-fallers in the same studies was 23% higher than the self-selected walking speed of the fallers (1.07±0.17). The ES for the speed of fallers and non-fallers for 10 studies was also high (-2.54±4.8). The difference in the Shimada's (2009) speed range and the mean of the walking speed in the reviewed studies could be due to the fact that the participants of his study were elderlies who needed long-term care and had some physical disability and frailty; however, in most of the studies in the current review the participants were defined as healthy elderlies.

Aging causes physiological changes that can affect walking. Some of these changes include decreased strength of the skeletal muscles, which is mostly the result of the reduction of the contractile tissue and muscle atrophy than a change in the motor unit activation pattern (50, 51). In elderly people this strength reduction causes a weak push off, which leads to a shorter step length and increased double support time (52). Moreover, it has been reported that fallers generate significantly less torque at the ankle while walking than non-fallers (14). This explains why, in most of the studies, the fallers had a shorter double support stance time than non-fallers. For example, in Nelson's study, the ES for the double support duration of fallers versus non-fallers was as high as 1.7.

Also, as aging happens, elderly individuals tend to give priority to stability rather than moving forward during walking.(53-55) For example, elderly people show less vigor in the push off, which can cause a shorter stride length that serves to reduce the amount of forward progression and longer stance double support time (52, 56, 57). This explains the shorter stride length and smaller cadence in the elderly.

The lack of flexibility and ROM and also strength can cause more variability in the gait of the elderly. Brach and Heitmann assessed the variability of step width in fallers and non-fallers. Brach found that fallers who walked at the near normal speed of □ 1.0m/s exhibited significantly higher step width variability than non-fallers, and that extremely low or high variability in step width is correlated with a history of fall ($p=0.006$). On the other hand, Heitmann found a negative low correlation (statistically significant, $p<0.05$) between most balance tests results (sharpened Romberg and one-legged stance) and step width variability ($p<0.05$), although he found no difference between the step width variability of walking in fallers vs. non-fallers. Gambell and Nayak proposed that higher step width variability is related to a lack of compensation for instability. That is, the fallers involved in Brach and Heitmann's study might have had reduced balance performance. Nevertheless, the ES and significance of the differences between fallers and non-fallers and the correlation of the history of fall and step width variability in the two studies is not considered to be high. Hence, more information than just step width variability is needed to decide the predisposition of an elderly to fall (11, 22, 58)

Among the temporal variability results, stance time variability had a high mean ES (0.9 ± 1.0), comparing the fallers vs. non-fallers in two studies by Brach and Hausdroff (11, 26). However, this difference was not statistically significant in the Brach's study (Figure 2).

Step length variability also exhibited conflicting results among different studies (11, 23). These differences in the results were mainly due to the test methodology employed in choosing the steps or the duration of the walking test.

Conclusion

Effect size analysis showed that stance time variability (ES=0.9±1.0), gait speed (2.5±4.8), stride length (ES=0.9±0.9) and step length (ES=5.7±11.3) were the spatio-temporal parameters that were the most different between elderly fallers and non-fallers (Figure 2). However, the mean and SD data for all variables was not available for all of the studies. As such, the presented effect sizes were the mean for the different number of studies, which ranged from two (stance time variability) to ten (gait speed).

Moreover, in the reviewed articles, the methodology and the subject selection criteria and definitions for discriminating fallers from non-fallers were not homogeneous. Hence, the ES results presented in this review are prone to some imprecision and could be referred to only as an overall perspective of the results of these studies. Moreover, in the majority of the parameters that were analyzed, the results of the studies were controversial. Thus, it seems that using only spatio-temporal analysis of level walking is not sufficient and cannot act as a reliable predictor of falls in elderly individuals.

Appendix A

Limitations for the search in the Embase data base:

- AND ([article]/lim OR [article in press]/lim OR [conference abstract]/lim OR [conference paper]/lim OR [conference review]/lim OR [review]/lim OR [short survey]/lim) AND ([gerontology and geriatrics]/lim OR [medical instrumentation]/lim OR [neurology and psychiatry]/lim OR [physiology and endocrinology]/lim OR [public health]/lim OR [rehabilitation]/lim OR [surgery]/lim OR [toxicology and drug dependence]/lim) AND ([adult]/lim OR [aged]/lim) AND [humans]/lim AND [1980-2013]/py

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Figure legend

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Table 1. Assessment form to choose articles.

Table 2. Specifications of the participants of the reviewed studies.

Table 3. The 17 reviewed studies' methodology and outcomes

TITLES OF FIGURES

Figure 1. Flow chart of the review process and search results.

Figure 2. Effect size introduced as Cohen's d is presented to show the standardized difference of fallers and non-fallers in the spatio-temporal parameters of gait, and the asterisks (*) indicate statistically significant differences.

Table 1. Assessment form to choose articles

1-1) Are there subjects over 60 years of age included as a separate group in the study?
2-1) Is there any grouping as elderly faller /non-faller or elderlies at high-risk / low-risk of fall?
2-2) Is the study retrospective in grouping faller's vs. non-fallers?
3-1) Are there at least one spatio-temporal measurement of gait?
3-2) Are there any comparisons in gait spatio-temporal parameters of elderly fallers vs. non-fallers?
3-3) Are the spatio-temporal measurements during the simple walking task?

Table 2. Specifications of the participants of the reviewed studies.

	Gender (n)	**Age years(mean and SD)**	**Participants(n)**	**Fall or faller definition**	**Inclusion criteria**	**Exclusion criteria**				
	Male	**Female**	**Faller**	**Non-faller**	**Total (SD or range)***	**Faller**	**Non-faller**			
Da Silva S. L. A	37	88	-	-	73.8(5.6)	43	82	History of fall in the past 12 months.	Age 65 years or older, residence in the community, and having answered the original Elderly Frailty Study Network inquiry.	Score below 17 on the Mini-Mental State Examination, severe effects of stroke, or being bedridden or restricted to a wheelchair.
Shimida H.	197	651	-	-	80 (73-91)	-	-	History of fall in the past year, using a self-report questionnaire. Fall: An event that resulted in a person coming to rest unintentionally on the ground or another lower level that did not result from a major intrinsic event or an overwhelming hazard.**	-	-No history of stroke hip OA Chronic obstructive pulmonary disease ones who could not use public transport independently -Ones who could not complete 6 gait trials of the gait test
Kojima M.	80	171	-	-	71.0(7.7)	39 -	191 -	Two or more falls in the previous year.	-	Physical condition, not being clear about the history of fall
Newstead A. H.	-	-	78.1(7.2)	75.8(5.1)	76.7(6.0)	18	30	History of at least one fall to the ground during the past year.	At least 60 years old, be able to walk 1 mile nonstop, and be free of neurological or orthopedic impairments that limited walking or	-

									stepping over an obstacle.	
Toulotte C.	0	40	70.4(6.4)	67.0(4.8)	68.8(5.7)	21	19	At least one fall occurred during the two years preceding the study. Falls resulting from unavoidable environmental hazards such as a chair collapsing were excluded. **	60 years or older and stable medical treatment (taken regularly and for at least three months).	Lower limb fracture or surgery, use of a walking aid or foot orthosis, cognitive disorders, auditory, ocular and/or vestibular problems, head trauma with or without loss of consciousness, stroke, disorder involving the upper limb, sores on lower limbs or feet and corns
Lee H.J.	12	12	76.9(5.8)	72.5(5.4)	74.7(5.6)	12 †	12	Experience of falls within a 2-year period prior to testing.	-	Significant head trauma, neurologic diseases, visual impairment not correctable with lenses, and musculoskeletal impairments
Brach J.S.	197	306	80.0(5.1)	79.1(3.9)	79.3(4.1)	81	422	Fall history (one or more) over the past 12 months (Did not include falls during skiing, skating, or other activities, such as walking on ice that may affect balance.) **	Individuals who were 65 years or older, non-institutionalized	Wheelchair bound in the home or were receiving hospice care, radiation therapy or chemotherapy for cancer
Mbourou A.M.	-	-	80 (74–91)	73(66–82)	76.7(66-91)	9	8	History of fall at least once in the last year. also the Berg Balance Test was given only to confirm the status of fallers	-	-
Auvinet B.	20	33	80.8(5.0)	77.2(6.5)	78.5(6.0)	20	33	Hospitalized for recent falls. They have been living at home and they have a history of fall of average 3.4(2.9), with an average of 3.6(0.4) falls during the preceding year.	-	-

Kerrigan D. C.	18	21	77(7.8)	73.2(5.6)	74.7(6.6)	16	23	At least 2 falls of unspecific cause within the previous 6 months, with at least 1 fall occurring while the person was walking on a level surface. **. falls secondary to syncope, acute illness, or other specific causes were excluded.	-	History of acute medical illness; diagnosis or symptoms of unstable angina or congestive heart failure; pulmonary diagnosis; neurologic diagnosis; major orthopedic diagnosis ; muscle weakness; corrected visual acuity worse than 20/100 or presence of a field defect; poor mental state (Mini-Mental Status examination score≤ 24/30); orthostatic hypotension; unilateral sensory deficit in lower extremities; bilateral sensory loss in stocking distribution or proprioception loss in the foot.
Gunter K. B.	26	131	75.4(5.1)	75.9(5.9)	77.4(5.5)	109	48	Faller and frequent faller based on the number of falls over the previous 12 month. Coming to rest on the ground as a clear result of an externally applied force (such as being struck by an automobile) or a specific neurological disorder (such as Parkinson's disease) was not recorded as a fall.	All subjects were living independently. Cognitively competent.	-
Nelson A.J.	5	19	79.4(8.7)	80.1(6.0)	79.8(7.3)	11	13	-	-	-
Eke-Okoro S.T.	4	5	74.8(1.7)	80.6(6.3)	78.0(4.9)	4	5	History of at least two falls within 4 months.	-	-
Lee L.W.	15	15	77.0(9.0)	75.0(5.0)	76.0(7.3)	15	15	At least two falls within a 6 months period from an unclear cause. not as a clear acute result of a specific	Ambulatory in the community.	-

								disorder such as a focal weakness, focal neuropathy, cardiac-related syncope, or active orthopedic problem **		
Hausdorff J. M.	14	21	82.2(4.9)	76.5(4.0)	79.4(4.5)	18	17	Persons who experienced a fall occurred during the past 5 years.	Subjects were considered eligible if they could walk unassisted for 6 minutes and if their overall medical condition was stable.	-
Heitmann D. K.	0	110	75.1(7.7)	73.1(7.0)	73.6(7.2)	26	84	At least one fall during the past year.	The subjects had to be able to walk 90 ft without an assistive device and to be independent in activities of daily living.	Institutionalized elderly women and volunteers with a diagnosis of a primary balance disorder, such as Parkinson's disease or multiple sclerosis, or with residual effects from a cerebrovascular accident were excluded from the study.
Gehlsen GM	19	36	72.4(4.7)	71.3(4.4)	71.8(4.5)	25	30	Had fallen 10 months or less before testing	Healthy elderly individuals without physical activity limitations.	Persons with disabling injuries to the leg and back were excluded. Uncontrolled hypertension, angina pectoris, recent myocardial infarction.

*pooled SDs are reported for the total age when they were not reported.

† 12 elderly patients with complaints of imbalance during walking, including 9 participants with a history of fall.

** indicates consideration regarding the environment and cause of fall in the fall definition.

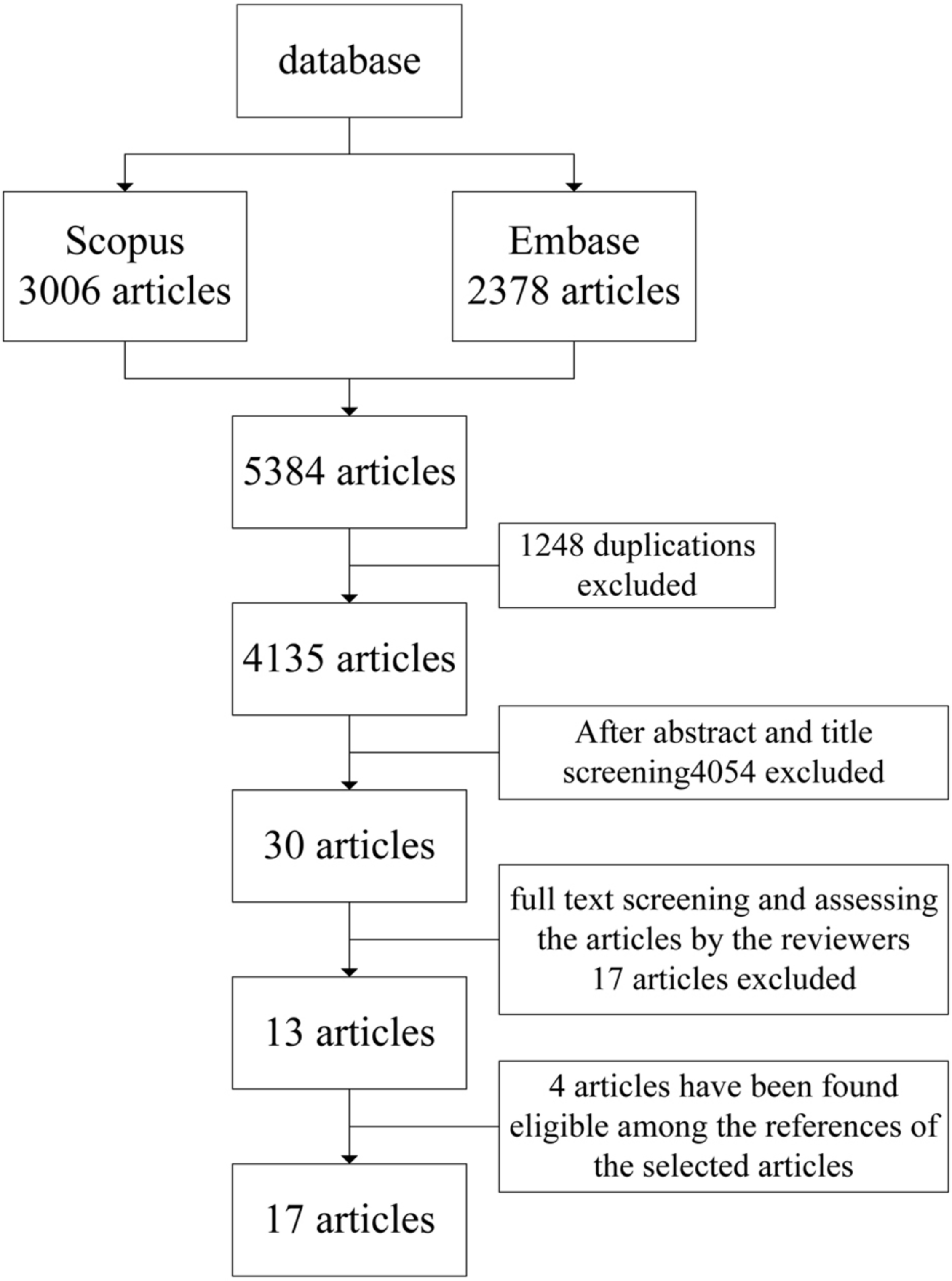
Table 3. The 17 reviewed studies' methodology and outcomes.

First author and Year	Study Design	Instruments	Tests	Saptio-temporal measurements	Findings
Da Silva S. L. A 2012	Cross sectiona l	GaitRite	Level walking on the mat	Percentage of double support and single support, base of support, cadence, stride length, step time, gait speed	-Frail and non-frail and frail and prefrail groups were significantly different in gait speed, cadence, step duration and stride length -No statistically significant difference were detected between fallers and non-fallers regarding gait speed, cadence, step duration, stride length.
Shimida H. 2010	Cross sectiona l	0.8×2.4 meter walkway device which measured the distribution of foot pressure during walking	Normal pace walking for 3 meters	Relationship between history of falls and gait speed, stride length, cadence, step width of left foot, gait pattern (long stride& cadence, short stride &slow cadence, …)	-A fast cadence increased the risk of fall, -A slow cadence combined with short stride increases the risk of fall.
Kojima M. 2008	Case control	Triaxial pisoelectric accelerometer	-Walking at comfortable and fats speeds for 11 meters	Comfortable and maximum walking speeds	Entropy comparison could distinguish between faller and non-fallers just in maximum walking speed and it's not discriminant in comfortable speed of walking.
Newstead A. H. 2007	Case control	6-camera Vicon Motion Analysis System, 4 Force plates.	Level walking at self-selected, slow and fast speeds	Single support, double support, second double support time, speed, cadence; step &stride length.	Fallers were different from non-fallers in self-selected and fast waling for all 7 measured gait parameters. They were most different in self-selected speed.
Toulotte C. 2006	Case control	6-camera Vicon Motion Analysis System, 3 force plates	10 single task tests (walking freely looking forward)	Cadence, speed, stride time, step time, single-support time; stride length and step length.	None of the gait parameters where different significantly between fallers and non-fallers.
Heng-Ju Lee 2006	Case control	6-camera motion analysis system, force plates	4 seconds data collection for level walking	Gait speed, stride length, step width; and sagittal and frontal center of mass (COM) and center of pressure (COP) inclination angles.	-Preferred gait speed was lower in fallers. -Stride length was significantly shorter in fallers. -Step width was not different.

					-At preferred walking speed, peak anterior COP-COM inclination angle was significantly smaller in fallers and peak medial inclination angle was significantly bigger for the fallers. -When walking at the similar gait speed (fallers self-selected and non-fallers self-selected slow speed) fallers demonstrated significantly greater medial inclination angle.
Brach J.S. 2005	Cross-s ectional	GaitMat II system	Self-selected walking speed on a 4m walkway	Gait speed and variability of step length, step width, step time and stance time.	-In elderlies with faster walking speed (≥0.1m/s) step width variability was significantly greater in fallers than non-fallers. - Step length, step time, stance time variability were not different in higher speed walking faller and non-faller elderlies. -In lower speed walking elderlies (≤0.1m/s), none of the gait variability parameters were different in fallers vs. non-fallers. -Elderlies with extremely high or low step width variability had fallen more than the ones with moderates step width variability.
Mbourou A.M. 2003	Case control	Length-voltage transducer by means of threads to measure length	Walking at preferred speed on a walkway(at least 3 stride in addition to the first step)	First step, first and second stride variability; First step length and first double support phase, step length and duration of single and double support phases.	-Elderly fallers had a much smaller first step length than non-fallers. -Fallers had a greater first step variability and greater time spent in double support in first stride. -In fallers the first stride was significantly shorter than the second stride which was not the case in non-fallers. -Fallers had greater second stride length variability than the non-faller. -Fallers spent significantly greater time in double support than non-fallers.
Auvinet B. 2003	Case control	LocometriX accelerometric gait analysis system(2 accelerometers)	Self-selected walking speed for 40m straight walking	Walking speed, stride length, frequency, regularity and symmetry.	- Walking speed, stride frequency and length and symmetry and regularity were all significantly different between faller and non-fallers. -The regularity index, which has been associated with risk of fall seemed to be the most relevant variable for predicting falls risk.
Kerrigan D. C.(a) 2001	Case control	Ooptoelectronic motion analysis system, force platforms	Walking at comfortable and fast speed	All major peak joint angles and pelvic position values; gait speed, cadence, stride length.	-Only peak hip extension significantly reduced in fallers compared to non-fallers. -Peak anterior pelvic tilt significantly increased with fast walking in fallers and it happened to non-fallers yet it was not significant.

Kerrigan D. C.(b) 2000	Case control	Video based 3D motion analysis system, 2 force plates	Walking at comfortable and fast speed on a 10m walkway	Gait Speed, Cadence , stride length.	-The comfortable speed of walking was significantly higher in non-fallers but fast speed of fallers were slightly higher than non-fallers -In comfortable walking stride length was reduced in fallers comparing to non-fallers but it slightly increased in fast walking and it was not significantly less than non- fallers.
Nelson A.J. 1999	Case control	GatRite	Four one-way pass on GatRite at preferred speed	Step/extremity length ratios (left and right), mean normalized speed, and step times, heel to heel base of support (BOS), and percent of gait in double support.	- Left and right step/extremity ration, mean normalized speed, step time, heel to heel BOS, double support percentage were significantly different among fallers and non-fallers. -Fallers had a greater variability in the gait. -Fallers had slower walking speed, lower bilateral step/extremity ratios, longer bilateral step time, wider heel-to-heel base of support and higher percentage of gait cycle spent in bilateral double support.
Eke-Okoro S.T. 2000	Case control	Stopwatch and counting the strides	Two trials on a 5-meter walkway, (5 fast to slow walking speeds)	Speed, stride length.	-Comparing to non-fallers the velocity field was occupied more with the very slow walking for fallers (91% versus 70% for non-fallers).
Lee L.W. 1999	Case control	Motion analysis system with four cameras and 2 force plates	Comfortable speed walking on a 30 foot walkway	Speed, cadence, step length.	-The speed of walking in the faller group was half of the non-faller group. - Cadence and step length of the faller group was 77% and 60% of the non-faller group, respectively.
Hausdorff J. M. 1997	Case control	Force sensitive foot switches inserted in right shoe.	6 minute walk at the self-determined pace.	Stride-to-stride variability, stride, stance and swing time, percent of stance time.	- Walking variability of stride time, stance time, swing time and percent of stance was higher in the fallers comparing to non-fallers. - The stride time variability in recent fallers was significantly greater than remote fallers. -The increased variability in fallers was not due to fatigue and not due to slowing down or speeding up. - Fallers and non-fallers were significantly different in stride time but other measures were not different.
Heitmann D. K. 1989	Case control	Footprints on a paper walkway	Typical speed walking of subjects on a 9 meter paper walkway	Mean and variability of step-width	There was no statistically significant difference between fallers and non-fallers in step-width variable.

Gehlsen GM 1990	Case control	Walking on the treadmill and filmed with two Locam cameras with internal tiimg device	Walking on treadmill at 4km/h and 6km/h	Stride frequency, stance time, swing time, double support time, stride length, heel width, heel height, toe height, hip, knee and ankle angular excursion.	-In either of the two walking speed, there was no significant difference between faller /non-faller in stride length(SL), SL/HT(height), SL/LL(leg length), heel height, toe height. - At 6km/h speed heel width was 13% greater in faller comparing to non-faller. Heel width was not different in slower speed of walking. - There was no significant difference between the two groups in any of the temporal gait variables. - No interaction of group and speed was found. - There was no significant difference between the two groups in the hip, knee and ankle joint excursion.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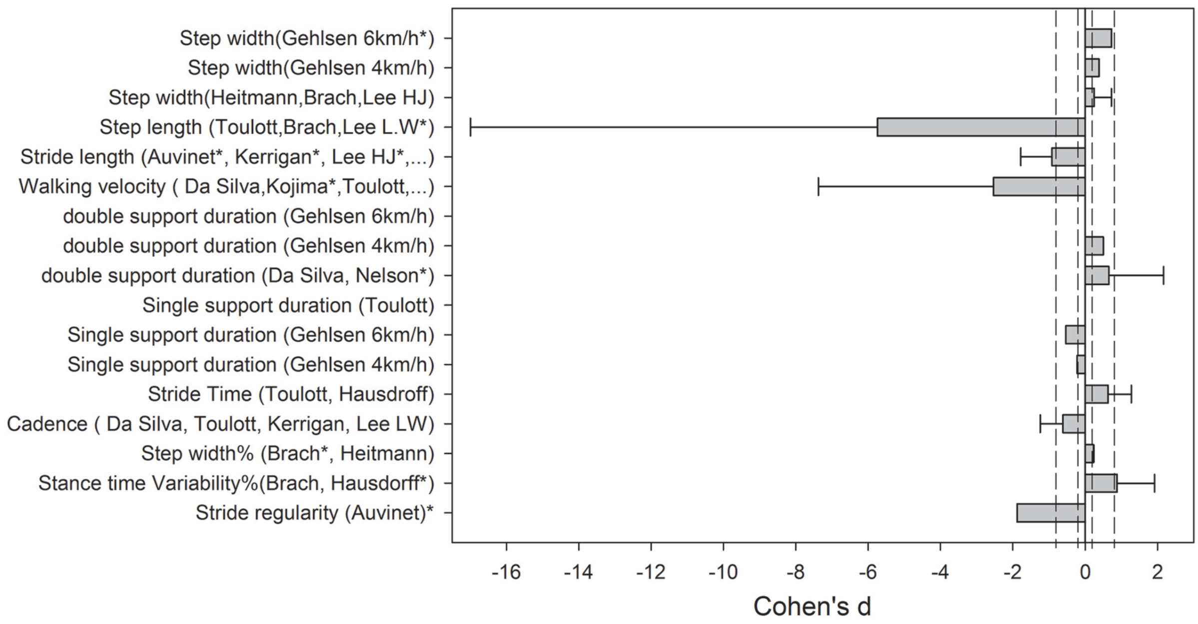
Step width(Gehlsen 6km/h*)
Step width(Gehlsen 4km/h)
Step width(Heitmann,Brach,Lee HJ)
Step length (Toulott,Brach,Lee L.W*)
Stride length (Auvinet*, Kerrigan*, Lee HJ*,...)
Walking velocity (Da Silva,Kojima*,Toulott,...)
double support duration (Gehlsen 6km/h)
double support duration (Gehlsen 4km/h)
double support duration (Da Silva, Nelson*)
Single support duration (Toulott)
Single support duration (Gehlsen 6km/h)
Single support duration (Gehlsen 4km/h)
Stride Time (Toulott, Hausdroff)
Cadence (Da Silva, Toulott, Kerrigan, Lee LW)
Step width% (Brach*, Heitmann)
Stance time Variability%(Brach, Hausdorff*)
Stride regularity (Auvinet)*
-16
-14
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