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Review

IS MUSCULAR AND FUNCTIONAL PERFORMANCE RELATED TO GAIT SYMMETRY IN OLDER ADULTS? A SYSTEMATIC REVIEW

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ABSTRACT

Background: Gait asymmetries are a matter of discussion concerning gait adaptation in older adults. While most studies perform unilateral gait assessments, the hypothesis that asymmetry in gait biomechanics is influenced by muscular and functional performance in older people needs to be confirmed.
Purpose: Here we performed a systematic review (CRD42018093189) to discuss the relationship between muscular and functional performance and gait asymmetries in older adults.
Materials and Methods: Searches were performed using Medline via Pubmed, Scopus, PEDro, Cochrane Central, and Lilacs databases. Studies investigating leg asymmetries during overground locomotion and recording kinetics, kinematics or muscular activation parameters to determine at least one muscular or functional parameter were included.
Results: Findings show that gait asymmetries, especially in step temporal parameters, are mainly related to functional outcomes, but the relationship with muscular performance was not possible to determine.
Conclusions: The relationship of gait asymmetry with muscular performance is still unknown, and there is a lack of investigations. Improvements in performance of functional tasks lead to a more symmetric gait.

1. INTRODUCTION

Aging is strongly associated with losses in muscle mass and strength (Baroni et al., 2013; Nilwik et al., 2013; Pereira et al., 2018; Seene, Kaasik, & Riso, 2012), resulting in poor performance of functional tasks (e.g. sit to stand and stair ascent and descent) (Butler, Menant, Tiedemann, & Lord, 2009; Nilwik et al., 2013). Lower gait speed (Hollman, Kovash, Kubik, & Linbo, 2007; Priest, Salamon, & Hollman, 2008), smaller step length, and longer stance phase (Cruz-Jimenez, 2017) also accounts for impairments in gait and balance, with important impacts on functional performance. Previous studies found aging associated with larger asymmetries in lower extremity muscle strength (Perry, Carville, Smith, Rutherford, & Newham, 2007; Schimidt, Machado, Vaz, & Carpes, 2014). Muscular and functional asymmetries are frequently advocated as a risk factor for falls (Di Fabio, Kurszewski, Jorgenson, & Kunz, 2004; Laroche, Cook, & Mackala, 2012), and a source of gait instabilities (Bautmans, Jansen, Van Keymolen, & Mets, 2011; Lewek, Poole, Johnson, Halawa, & Huang, 2010).

Lower limbs strength, power, rate of torque development, and muscle activation (Kirkwood, Trede, Moreira Bde, Kirkwood, & Pereira, 2011; LaRoche, Cremin, Greenleaf, & Croce, 2010; Perry et al., 2007) are considered potential tools in screening for risk of falls, but only a few studies actually addressed the relationship between muscular and functional parameters with gait asymmetries. Neuromuscular parameters, such as knee extensor strength, are the most frequent explanation to asymmetries in gait (Laroche et al., 2012; Schimidt et al., 2014). Asymmetrical lower limb strength (i.e. knee extension strength) may increase gait variability (Laroche et al., 2012), which is also related to a greater risk of falls among older adults Additionally, asymmetries in knee extension power were related to lower walking speed in old women (Portegijs et al., 2005). Such muscular parameters are also fundamental components of functional performance in the older adult. Functional performance is often evaluated considering gait-related tasks. Assuming that gait is cyclical, limb symmetry is also often assumed, which can make sense to simple tasks of walking, but not when more challenging tasks are considered, i.e., when task complexity increases (Kowalski, Catelli, & Lamontagne, 2019). Functional

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performance may also depend on the speed of movement, as a lower gait speed seems to be a source of differences in gait between older fallers and non-fallers (Huijben, van Schooten, van Dieen, & Pijnappels, 2018). In this regard, higher functionality depicted by higher gait speed was associated with a more symmetric gait (Huijben et al., 2018). The understanding of possible muscular and functional factors explaining gait asymmetries may help to plan strategies (in rehabilitation and physical exercise programs) to reduce asymmetries suggested as a risk for falls in old individuals as we already mentioned.

Therefore, as an attempt to determine whether gait asymmetries observed in cross-sectional studies considering older adults can be explained or discussed with basis on muscular (those parameters related to muscle structure and strength production, e.g. muscle thickness, strength, power and muscle activation) and functional performance (those global tests that consider both limbs working together) of the lower limbs in the old adults, and to gather the existing studies on this topic, we performed a systematic review of the literature. The aim of this systematic review is to investigate whether functional and muscular lower limb parameters are related to gait symmetry in old individuals. Initially, we considerrd only the association between gait asymmetries and asymmetries in muscular and functional parameters. However, due to the reduced number of studies found, we considered also the global muscular and functional parameters and their association with gait asymmetries.

2. MATERIALS AND METHODS

2.1. Design and Search Strategy

We performed a systematic review of cross-sectional studies, following the PRISMA Statement recommendations. This review was registered at the International Prospective Register of Systematic Reviews – PROSPERO (CRD42018093189), available from http://www.crd.york.ac.uk/PROSPERO.

Searches were performed in five databases: Medline via Pubmed, Scopus, PEDro, Cochrane Central, and Lilacs. These searches were performed articles published since the beginning of the databases until November 2018. Targeted searching of frequently cited journals, authors and article reference lists were checked to ensure that all relevant articles could be find. Mesh terms (and synonyms) and keywords related to the population, the outcomes, and asymmetries were used for the searches combined with the Boolean terms "AND" and "OR", as follow: ("gait" OR "locomotion" OR "walking" OR "walk") AND ("asymmetry") AND ("elderly" OR "older") for the Pubmed and Scopus databases, and using the terms (gait AND asymmetry) for the remaining databases without using filters.

2.2. Eligibility Criteria

We included cross-sectional studies investigating leg asymmetries during independent overground locomotion through kinetics, kinematics or muscular activation parameters in older individuals (over 65 years, both men and women) and measuring at least one muscular or functional parameter. Studies analyzing treadmill walking and/or that did not present results for each lower limb separately or did not present an asymmetry index were excluded. Only articles published in English language were considered.

2.3. Study Selection

The initial yield was obtained by combining all original articles from the different electronic databases and targeted searches. Search results were exported to a database including their titles and abstracts. The search results was analyzed by at least two independent reviewers (ECG and LS), which selected the papers considered for the full-text analysis. Papers selected by at least one reviewer had the full-text downloaded and two independent reviewers (ECG and LS) applied the eligibility criteria. A set of guidelines and examples for completing article reviews was provided for both reviewers to improve inter-reviewer reliability. A third reviewer (FAB or FPC) solved discrepancies. The studies that full-filled all criteria were included in the systematic review.

2.4. Data Extraction

Data extraction was performed by two independent reviewers (ECG and LS), and revised by two other reviewers (FAB and FPC), who also solved discrepancies between the reviewers. As differences in terminology may exist between studies, a list of synonyms for spatial-temporal variables of gait (step or stride length and width, stride time, speed, velocity, acceleration, spatiotemporal and spatial-temporal) was used for each key term to identify all relevant articles. Data of participants, gait parameters, and functional and muscular parameters were extracted through a standardized form. Results from each lower limb and asymmetry values were also extracted. For papers that included other groups of participants (e.g. Parkinson's disease), only the results from healthy older participants were extracted. When the way the data were presented in the study did not permit to extract the results, the missing information was requested to the corresponding author of the study.

2.5. Methodological Quality

Two authors (ECG and LS) performed the methodological quality assessment of each included study using an adapted model from Galna et al. and Barrett et al. (Barrett, Mills, & Begg, 2010; Galna, Peters, Murphy, & Morris, 2009). This tool considers 13 items related to the study capacity to avoid potential bias, including research aim question, participants' characteristics, inclusion and details regarding exclusion criteria and sampling methods, different aspects of the methods, results and main applications. The maximal score is 13 points and we considered those studies with a minimal score of 7 points as with a good quality.

2.6. Data Analyses

A qualitative descriptive analysis was performed considering the main characteristics of the participants from each study, and the results found for muscular, functional and gait parameters.

3. RESULTS

3.1. Selection of the studies

The first search returned 894 papers, among which 137 were selected for full-text analysis. After the analysis, 78 papers were evaluated according to the elegibility criteria application, resulting in the inclusion of 5 papers in this systematic review. Fig. 1 describes the complete process of search and selection of the studies.

3.2. Main characteristics of the studies

Considering the 5 studies included, 2448 subjects were investigated. All papers included both men and women as participants. The gait evaluations were performed mostly at self-selected gait speed, and one study also investigated cognitive dual-task and none analyzed gait asymmetry during obstacle crossing. Only one study analyzed kinetic parameters of gait, while four studies considered spatial and/or temporal parameters from kinematics assessment. In this sense, step length and step time, and the swing time and stance time were the most common variables across the studies. The way each of the included studies determined gait asymmetry is detailed in the Supplementary

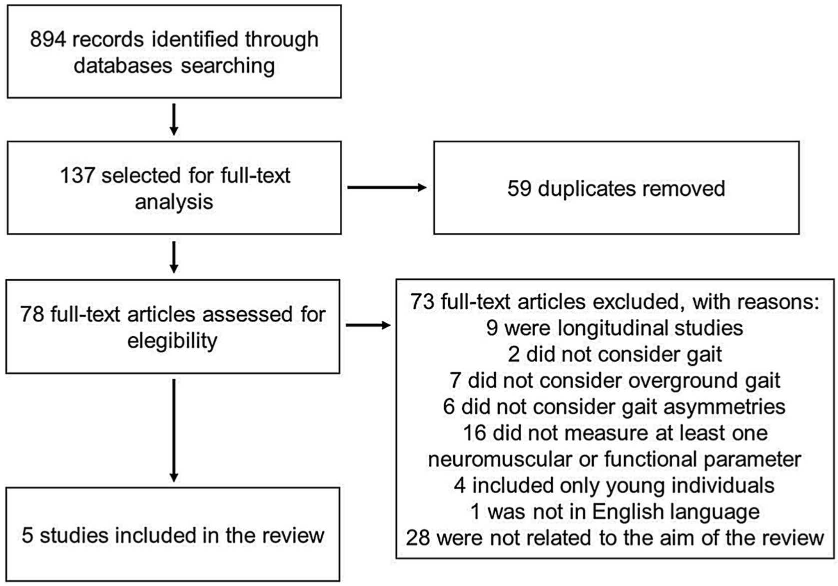

Fig. 1. Flowchart of the studies found and screened in this systematic review.

File 1. Electromyography assessment of gait was not performed by the included studies. Several functional and muscular parameters were investigated in the included studies (e.g. balance, sit-to-stand). Table 1 details the data reported by each study.

3.3. Main results from each study

Asymmetry in temporal step parameters (Bautmans et al., 2011; Egerton, Paterson, & Helbostad, 2017; Yogev, Plotnik, Peretz, Giladi, & Hausdorff, 2007), such as step, stance and swing time, is related to muscular and functional lower limb parameters (Fig. 2 and Table 2). However, due to the variability among the studies, we opted to briefly report their main findings. Fig. 2 presents a summary of systematic review findings.

Bautmans et al. (2011) found negative correlations between asymmetry in step time during walking at self-selected speed and handgrip work ($r = -0.22$; $p < 0.05$) and Tinetti gait test ($r = -0.34$; $p < 0.01$) in older men and women (fallers and non-fallers). However, asymmetry in step time did not correlate with handgrip strength ($r = -0.11$; $p > 0.05$), timed-and-up go test (TUG) ($r = 0.14$; $p > 0.05$) and Tinetti balance test ($r = -0.15$; $p > 0.05$).

Physical activity measures (overall activity, amount of high intensity activity and walking activity) were not associated with asymmetries in step length, stance and swing time, while walking at preferred gait speed, with all values of regression analyses being lower than 0.1 (Egerton et al., 2017). On the other hand, there were associations between stance time asymmetry and minutes of high intensity activity per day ($r^2 = -0.10$), and number of steps per day ($r^2 = -0.11$), when gait was analyzed at fast speed, but only for women. Only step length asymmetry was associated with minutes of high intensity activity per day in men walking at fast speed ($r^2 = -0.11$).

In the study of Lord et al. (2013), asymmetries in step length (0.02 ± 0.017 m), step time (11.3 ± 11.4 ms), step stance (8.9 ± 9.3 ms) and step swing time (8.9 ± 9.4 ms) were reported. Asymmetry were determined considering the absolute (always positive) difference between values from the right and the left limbs, for each parameter measured. Functional assessment of balance included single leg 30 s stance (right 15.6 ± 12.5 s; left: 14.6 ± 12.0 s) and timed chair stand (12.3 ± 4.0 s). They found asymmetries in balance, but association between the variables was not tested. However, it was possible to observe that asymmetries were present in single balance and also during gait.

Riskowski, Hagedorn, Dufour, & Hannan (2012) found asymmetries in peak vertical force at toes, forefoot, arch and rearfoot, and forefoot-to-rearfoot force ratio. Furthermore, they reported the asymmetries in peak vertical forces increasing in response to increases in gait speed. Considering functional parameters, those participants showing lower asymmetry in forefoot-to-rearfoot force ratio also presented the best results in functional tests (tandem balance, gait speed and chair stand).

Finally, Yogev et al. (2007) found inverse correlations between swing time asymmetry and gait speed in conditions with ($r = -0.37$; $p = 0.012$) and without performance of a dual-task ($r = -0.50$; $p = 0.001$). It is important to note that these correlations were determined considering average values from fallers, non-fallers and patients with Parkinson's disease, which may have influenced the outcomes.

3.4. Quality assessment

Table 2 shows the main results from quality assessment. The full results of quality assessment are available in the Supplementary File 2. All studies presented a good quality (score greater than 7 points), with a total score average of 11.25 points, from a total of 13 points possible. In general, the studies did not receive the total score for the following aspects: missing details of the participants; recruitment and sampling methods; key outcomes description; internal validity of the methodology; and practical implications of the results found.

4. DISCUSSION

In this systematic review we set out to determine whether muscular and functional performance could explain gait asymmetry in older adults. Gait asymmetries are frequently discussed as resultant of unbalances in muscular function, but a lack of studies testing this hypothesis is evident in the literature. Most of studies consider or muscular or functional outcomes, but do not combine them in the study of asymmetries in locomotion. Despite the limited number of manuscripts satisfying the inclusion criteria in our review, all of them presented a good quality (Table 2). Interestingly, when muscular and functional parameters are considered, gait asymmetries were related to outcomes from functional assessments. Asymmetries in step temporal parameters were more often related to functional performance outcomes (Fig. 2). Greater asymmetry in step spatial parameters only was related to a worse functional outcome for men. In addition, kinetic asymmetries

Table 1
Characteristics of the included studies regarding the participants, gait evaluation, and functional and muscular parameters considered in the assessment of older participants. All studies included both women and men as participants.

Study	Number of participants	Age	Gait evaluation	Functional and muscular outcomes
Bautmans et al. (2011)	81	OFR: 80.6 ± 5.4 OC: 79.1 ± 4.9	Comfortable speed along 18 m; Outcome: step time	Grip strength, endurance and work, TUG and Tinetti balance and gait[a]
Egerton et al. (2017)	1223	73.4 ± 1.9	Two conditions: preferred and fast speed along 8.7 m; Outcomes: step length, stance time and swing time	Overall activity (counts), amount of high intensity activity (minutes) and walking activity (steps/day)
Lord et al. (2013)	189	69.5 ± 7.6	Preferred speed along 25 m; Outcomes: step length, step time, step stance and step swing time	Balance (single leg stance) and timed chair stand
Riskowski et al. (2012)	929	73.0 ± 10.6	Self-selected speed, distance not informed; Outcomes: peak vertical force at toes, forefoot, arch and rearfoot, and forefoot-to-rearfoot force ratio	Static balance (side-by-side, semi-tandem and tandem; capacity to maintain each position up to 10 s), gait speed (4 m) and 5-times-chair stand (time to stand as quickly as possible from a chair)
Yogev et al. (2007)	26	FF: 76.3 ± 4.9 NF: 67.5 ± 3.5	Comfortable pace along 25 m; two conditions: baseline and dual-task (arithmetic task); Outcome: swing time	Gait speed (8 m)

OFR: older with increased fall risk; OC: old controls; FF: fallers; NF: non-fallers. *Age is the mean value reported by the authors.
[a] (Tinetti, 1986).

were analyzed only in one study, showing these asymmetries also related to the functional parameters (Table 2). Therefore, we suggest that functional impairments could be a source for gait asymmetries. However, this finding should be analyzed carefully because important components of movement production and control like the angular kinematics, strength, power, muscle structure, and muscle activation were not considered in the studies included in this review.

The asymmetry in temporal step parameters is mainly related to muscular and functional outcomes. Yogev et al. verified that swing time asymmetry presents an inverse relation with gait speed (Yogev et al., 2007). This is in accordance with the idea that step asymmetries are negatively influenced by gait speed. Asymmetry in swing time could be caused either by the difficult to transfer the lead limb forward or by the difficult of the stance limb in maintain the balance while the lead limb performs the swing phase. It is known that gait speed influences important parameters of gait (e.g. step length and step time), and as recently suggested, higher gait speed may favor better symmetry (Huijben et al., 2018). In addition, asymmetry in temporal step parameters is increased among elderly idiopathic fallers, compared with controls (Yogev et al., 2007). However, it is necessary to highlight that this correlation was found for a group of older adults including fallers, non-fallers, and older with Parkinson's disease. Differences in gait among these groups are reported in the literature (Kwon, Kwon, Park, & Kim, 2018; Newstead, Walden, & Gitter, 2007; Yogev et al., 2007), and therefore may have an influence on the results.

The association between risk of falls and gait asymmetries is frequently mentioned in the literature. For example, asymmetric movements related to toe clearance, like vertical footlift velocity during obstacle crossing, were found in older adults classified at high risk of falls (Di Fabio et al., 2004), and also differed between active and sedentary elderly (Guadagnin, da Rocha, Mota, & Carpes, 2015). Asymmetry in lower limb strength was found among older adults showing higher gait variability (Laroche et al., 2012). Not only asymmetry of strength, but also of power output, mainly for knee extension, were found in older adults with risk or history of fall, however gait asymmetries were not considered in these studies (Perry et al., 2007; Portegijs et al., 2005). Lower extremity strength (Crockett et al., 2013) and power (Bean et al., 2010) are factors determining functionality in the older adults and therefore are important components of health in this population. It may suggest that older adults with impairment in functional performance may also have bilateral asymmetries in the muscular performance. Furthermore, our results depict a lack of investigations addressing the relationship between muscular and functional parameters and gait asymmetries in old adults.

An important component of independence in the older adult is the gait speed, and most of the training regimes conducted in old adult are aiming at improve gait speed, which was recently suggested to improve quality of gait (Huijben et al., 2018). However, it is not clear to what extent the increase of gait speed is safe to the old adult. In young adults and athletes, the increase in the rate of movement execution (walking speed, pedaling cadence) is in general related to lower asymmetry in biomechanics parameters between the lower limbs (Carpes, Mota, & Faria, 2010). In older adults, higher gait speed elicited larger asymmetries in ground reactions forces considering different foot regions (Riskowski et al., 2012). If we extrapolate this finding to the daily life of the older adult engaged in regular walking or running exercises, the cumulative asymmetric pressure loading on the foot, verified in old individuals (Franco, Silva, Rocha, & Carpes, 2015), could be a risk factor for stress injuries in the foot (Mandell, Khurana, & Smith, 2017). Furthermore, an asymmetric loading could be related to the presence of heel pain and other pathologies in the older adult's feet (Wafai, Zayegh, Woulfe, Aziz, & Begg, 2015). Despite the fact that subjects able to walk faster are considered with a better functional condition, the effort necessary to control the locomotor system when it is necessary to walk at maximal speed is greater, which could explain the presence of asymmetries in the older adult (Riskowski et al., 2012).

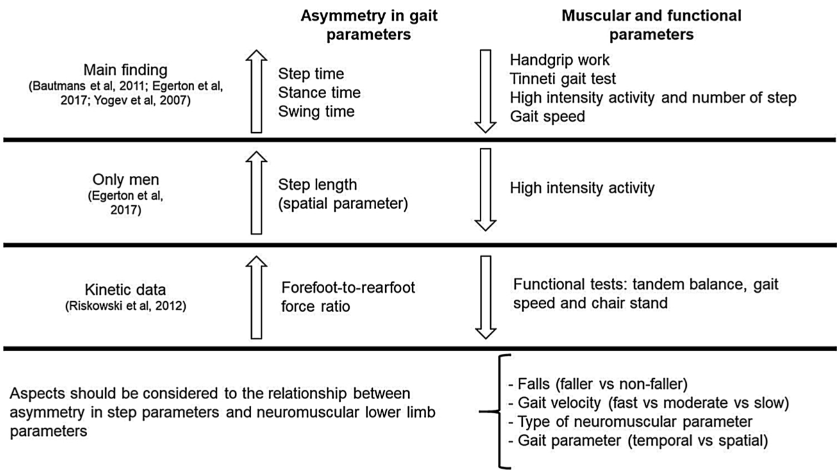

Fig. 2. Summary of the relationship between functional and muscular lower limb parameters and gait symmetry in old individuals. The bottom line indicates aspects that should be considered to understand the relationship between functional and muscular lower limb parameters and gait symmetry in old individuals. Arrows indicate that when asymmetries are present in gait parameters (second column) there is also a deterioration in muscular and functional parameters (third column).

Regular exercise is related to a more symmetric gait in older adults (Guadagnin et al., 2015). However, the relationship between global level of physical activity with gait asymmetries is not clearly stablished. Egerton et al. found an inverse relation of gait asymmetry and minutes of high intensity activity per day, but no relation with the quantity of activity per day (Egerton et al., 2017). We suggest the need to perform activities at higher level of intensity in order to have a more symmetric step length, which is related to a reduced risk of falls (Di Fabio et al., 2004; Laroche et al., 2012). The amount of physical activity per day did not influence stance time and step length asymmetry at preferred gait speed (Egerton et al., 2017). However, when participants were tested at fast walking speeds, which are more challenging, larger asymmetry in stance time indicated lower time of high intensity activity and a smaller number of steps per day (Egerton et al., 2017). These negative associations between asymmetry and minutes of high intensity activity may suggest that low intensity activity is associated with asymmetries, which in fact can make sense because low intensity activities of daily life not necessary will result in improvement of physical conditioning.

Table 2
Main results from quality assessment (13 was the maximal score of quality).

Study	Gait parameter	Relation	Muscular and functional outcomes	Quality assessment score
Bautmans et al. (2011)	Step time asymmetry	No	Handgrip strength	12.35
		No	TUG	
		No	Tinetti test – balance	
		(-)	Handgrip work	
		(-)	Tinetti test – gait	
Egerton et al. (2017)	Step length asymmetry (PS)	No	Overall activity	10.65
		No	Minutes of high intensity activity per day	
		No	Number of steps per day	
	Step length asymmetry (FS)	No	Overall activity	
		(-)	Minutes of high intensity activity per day (only for men)	
		No	Number of steps per day	
	Swing time asymmetry (PS)	No	Overall activity	
		No	Minutes of high intensity activity per day	
		No	Number of steps per day	
	Swing time asymmetry (FS)	No	Overall activity	
		No	Minutes of high intensity activity per day	
		No	Number of steps per day	
	Stance time asymmetry (PS)	No	Overall activity	
		No	Minutes of high intensity activity per day	
		No	Number of steps per day	
	Stance time asymmetry (FS)	No	Overall activity	
		(-)	Minutes of high intensity activity per day (only for women)	
		(-)	Number of steps per day (only for women)	
Lord et al. (2013)	Step length Step time Stance time Swing time	Not tested	Single leg stance Timed chair stand	12.05
Riskowski et al. (2012)	Asymmetry in peak vertical force at: Toes Forefoot Rearfoot	(+)	Gait speed	11.15
		(+)	Gait speed	
		(+)	Gait speed	
	Forefoot-to-rearfoot force ratio asymmetry	(-)	Gait speed	
		(+)	Chair stand	
		No	Static balance (side-by-side)	
		No	Static balance (semi-tandem)	
		(-)	Static balance (tandem)	
Yogev et al. (2007)	Swing time asymmetry	(-)	Gait speed	10.05

No: non-significant correlation; (-) significant negative or inverse relation; (+) significant positive or direct relation; PS: preferred speed; FS: fast speed.

We could also explain these association based in the relationship between step time asymmetry and measures of balance, handgrip and timed up and go performance that benefit of a higher physical conditioning (Bautmans et al., 2011).

5. CONCLUSIONS

Based in our systematic review of the literature, we conclude that gait symmetry is mainly related to functional outcomes in the older adult. Influence of muscular parameters (muscle structure, activation and strength related outcomes) on gait asymmetries were not possible to establish due to the lack of studies. It is possible to speculate that an improvement in functionality could lead to a more symmetric gait, reducing the risk of falls. In addition, asymmetry in temporal step parameters seem to be more affected by muscular and functional lower limb parameters.

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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.archger.2019.103899.

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