Gait & Posture 93 (2022) 83–89

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Components of gait in people with and without mild cognitive impairment

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ARTICLE INFO

Keywords:
Mild cognitive impairment
Gait analysis
Gait components
Gait variability
Principal component analysis

ABSTRACT

Background: Several objective gait parameters are associated with cognitive impairment, but there is limited knowledge of gait models in people with mild cognitive impairment (MCI).
Research question: How can 18 objective gait characteristics be used to define different components of gait in people with MCI (with suspected incipient neurocognitive disorder) and cognitively unimpaired people (CU), respectively?
Methods: Spatiotemporal gait data were collected by using an electronic walkway (GAITRite®), i.e. assessments in comfortable gait speed. Using cross-sectional gait data, two principal component analyses (PCA) were performed (varimax rotation) to define different components of gait in people with MCI (n = 114) and CU (n = 219), respectively, from the BioFINDER-2 study.
Results: Both PCAs produced four components, here called *Variability, Pace/Stability, Rhythm* and *Asymmetry*. Total variance explained was 81.0% (MCI) versus 80.3% (CU). The Variability component explained the largest amount of variance (about 25%) in both groups. The highest loading gait parameter was the same for both groups in three out of four components, i.e. step velocity variability (Variability), mean step length (Pace/Stability) and mean step time (Rhythm). In the asymmetry component, stance time asymmetry (MCI) and swing time asymmetry (CU) loaded the highest.
Significance: The gait components seem similar in people with and without MCI, although there were some differences. This study may aid the identification of gait variables that represent different components of gait. Gait parameters such as step velocity variability, mean step length, mean step time as well as swing and stance time asymmetry could serve as interesting core variables of different gait components in future research in people with MCI (with suspected incipient neurocognitive disorder) and CU. However, the selection of gait variables depends on the purpose. It needs to be noted that assessment of variability measures requires more advanced technology than is usually used in the clinic.

1. Introduction

Reduced gait speed is associated with future cognitive decline/dementia [1–5], but other gait variables may be more sensitive out of a diagnostic and prognostic view [6–8]. For example, gait variability is suggested to be a more precise marker of cognitive decline [6], and double support time (DST) variability seems to predict memory decline [7]. While gait speed is easily measured, other spatiotemporal gait parameters require more advanced technology (e.g. wearable sensors or an electronic walkway) [9,10]. Such technology generates a large number of gait variables. When selecting core gait variables for use in research and clinical settings, it is important to have a conceptual understanding of gait. This can be achieved by using principal component analysis (PCA).

Several studies have explored underlying components of gait by using PCA in older adults without dementia. All of these identified the

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https://doi.org/10.1016/j.gaitpost.2022.01.012
Received 17 November 2021; Received in revised form 5 January 2022; Accepted 14 January 2022
Available online 17 January 2022

components pace, rhythm and variability [11–17]. Some also identified additional components, e.g. phases and base of support [13,15,16]. Few studies included asymmetry measures [14,17]. Lord et al. studied 16 gait parameters, including four asymmetry measures, and five components were defined: pace; rhythm; variability; postural control; and asymmetry [14].

When addressing gait as single task, several gait parameters can differentiate between cognitively unimpaired people and those with mild cognitive impairment (MCI); people with MCI exhibit for example a decreased gait speed, stride length and stride time as well as a longer double support time and an increased variability of different gait parameters [18,19].

To our knowledge, only one prior study explicitly explored components of gait in people with MCI [20]. Pieruccini-Faria et al. analyzed seven gait parameters and identified three components of gait (pace; rhythm; variability). Their gait data was based on strides instead of steps [20]. However, the use of steps enables the inclusion of asymmetry measures and has been suggested to improve the reliability of variability measures [21]. Consequently, more studies are needed that examine components of gait in people with MCI.

This study aimed to define different components of gait as a single task by exploring 18 objective gait characteristics at comfortable gait speed in people with MCI (with signs of an incipient neurocognitive disorder) and cognitively unimpaired (CU) people. The gait parameters were based on steps and included the 16 parameters used by Lord et al. [14] and two additional parameters, i.e. double support time and double support time variability.

2. Methods

2.1. Study context and participants

This cross-sectional study used data collected (2017–2020) in Motor-ACT (Motor aspects and activities in relation to cognitive decline), which is a sub study to the larger BioFINDER-2 study (Biomarkers for identifying neurodegenerative disorders early and reliably; NCT03174938). Motor-ACT included participants from two of the BioFINDER-2 cohorts: i) cognitively healthy persons, and ii) people with MCI or subjective cognitive decline (SCD). All participants in Motor-ACT were recruited from Skåne University Hospital (Sweden).

Inclusion and exclusion criteria for both cohorts in Motor-ACT are identical to those in BioFINDER-2, which have been described previously [22,23]. In summary, inclusion criteria for cognitively healthy persons were: age 66–100 years; absence of cognitive symptoms assessed by a physician with special interest in cognitive disorders; speaks and understands Swedish fluently; Mini Mental State Examination (MMSE) score $\geq$ 26 at the screening visit for BioFINDER-2; and do not fulfill the Diagnostic and Statistical Manual of Mental Disorders 5th revision (DSM-5) criteria for minor (i.e. MCI) or major (i.e. dementia) neurocognitive disorder [24]. Cognitively healthy persons, i.e. those who were recruited to the study as healthy controls, were screened by a physician with special interest in cognitive disorders to verify that they had absence of cognitive symptoms. The physician's assessment was based on anamnesis, the Brief Anasognosia Scale (BAS), the Cognitive Function Instrument (CFI) as well as the Cognitive Impairment Questionnaire (CIMP-QUEST). The participants were also assessed with more detailed and thorough cognitive assessments, see below.

Inclusion criteria for people with SCD or MCI were: age 40–100 years; speaks and understands Swedish fluently; and referred to a memory clinic due to cognitive symptoms. At the screening visit for BioFINDER-2, their MMSE score should be $\geq$ 24 and they should not fulfill the DSM-5 criteria for major neurocognitive disorder (i.e. dementia) [24].

All participants underwent thorough cognitive assessments. Attention and executive function were assessed with the Trail Making Test A and B (TMT), and the Symbol Digit Modalities Test (SDMT). Visuospatial ability was measured by using incomplete letters and cube analysis from the Visual Objects and Space Perception (VOSP) battery. Memory was assessed using the 10-word delayed recall test from ADAS-cog. Verbal ability was assessed using animal fluency and the 15-item short version of the Boston Naming Test. Raw test scores were transformed to z-scores based on the performance in a healthy control sample without signs of Alzheimer pathology (cerebrospinal fluid [CSF] Aβ and P-tau) by using a linear regression-based method, adjusted for age and education if significant [25,26]. Scores were then averaged for each cognitive domain. Participants were classified as having MCI if performing worse than − 1.5 z-score in at least one cognitive domain (attention/execution, memory, verbal ability or visuospatial function), in agreement with the Petersen MCI criteria [27]. Those who had been referred to the memory clinic because of cognitive complaints but performed − 1.5 z-score or better in all cognitive domains were classified as having SCD, in agreement with SCD criteria [28]. Furthermore, Motor-ACT only included persons with SCD or MCI where the physician suspected that the cognitive complaints were caused by an underlying neurodegenerative disease. This was operationalized as having either an abnormal CSF Aβ42/40 ratio, increased CSF neurofilament light (Nfl), or any core criteria of dementia with Lewy bodies [24].

Exclusion criteria for both subgroups were: unstable systemic illness hampering participation; current significant alcohol/substance misuse; or refusing lumbar puncture/Magnetic Resonance Imaging/Positron Emission Tomography (data not used in the present study). For the cognitively healthy group, significant neurological or psychiatric illness composed an additional exclusion criterion.

The current study had additional exclusion criteria: having obtained a neurodegenerative disorder (n = 11) or having progressed to a symptomatic vascular dementia prior to gait assessments (n = 1) according to their treating physician (medical records were screened); using walking aids during assessment (n = 11); or walking < 30 steps on the electronic walkway (n = 17) [21]. One additional participant was excluded due to hemiparetic gait. Fig. 1 presents a flow chart of the recruitment procedure.

Following the recommendations of the US National Institute on Aging–Alzheimer's Association guidelines [29], cognitively healthy persons and those with SCD were pooled to the CU group. The final sample size was 114 participants with MCI and 219 CU (SCD, n = 76;

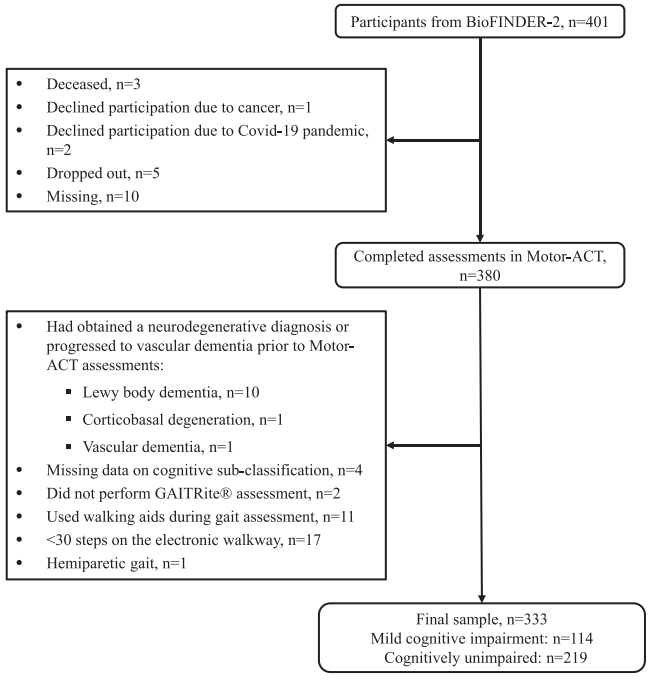

Fig. 1. Flowchart of the inclusion process of participants.

cognitively healthy persons, n = 143), see Table 1 for participant characteristics.

Written informed consent was obtained from all study participants before the start of the study. Ethical approval was obtained by the Regional Ethical Review Board in Lund (2016–1053) and the Swedish Ethical Review Authority (2019–02681).

2.2. Gait assessment

Gait assessments were performed by three physiotherapists. This occurred in conjunction to the baseline evaluation in BioFINDER-2 for cognitively healthy persons and to the 1-year follow-up evaluation (mean time=288 days, SD=42.9) for participants with MCI and SCD.

Objective spatiotemporal gait parameters were measured using an electronic walkway (GAITRite® platinum, CIR Systems Inc.). Active mat length was 4.88 m and width 0.69 m (total mat length: 5.79 m; width: 0.89 m), including > 18,000 sensors; 120 Hz sampling rate [30]. Participants were instructed to walk six continuous laps on the walkway at a comfortable, self-selected speed. After stepping off the walkway, they rounded a cone and returned walking alongside the walkway. Participants rounded another cone leading towards the walkway again. There was at least 1.5 m free walking space before and after the walkway to permit acceleration and deceleration.

2.3. Gait parameters

The GAITRite® software generates a multitude of objective gait parameters. We included 18 parameters (mean, variability and asymmetry measures) in the initial analyses (see Table 2). The selection was based on prior gait analysis studies [11–17,20], particularly the study by Lord et al. [14]; but we also included DST measures as they seem to predict cognitive decline [8,31].

Mean step velocity was calculated as step length divided by step time, using individual step data, as step velocity is not produced by the GAITRite® software. Step velocity variability was calculated using the within-person standard deviation of left and right steps [21]. Other gait measures were calculated using summary data for the left and right foot respectively, provided by the software.

2.4. Descriptive data

Descriptive data (Table 1) included age, sex, educational level (years) and body mass index. Additional data included global cognitive functioning (MMSE; range=0–30; higher=better), presence of the APOE e4 allele on either of the chromosomes 24, 34, 44, 42 or 43 (yes/no), depressive symptoms (Hospital Anxiety and Depression Scale, depression subscale; range 0–21; higher=worse), fear of falling (yes/no) and having fallen during the past 12 months (yes/no). The presence of comorbidities (yes/no) included hypertension, diabetes, ischemic heart disease and stroke/transient ischemic attack. Descriptive data of gait parameters is presented in Table 3.

2.5. Statistical analysis

Differences in gait parameters between the MCI and CU groups were analyzed using independent samples t-tests and Mann Whitney U-test, depending on data level. Bonferroni correction was used in order to adjust for multiple comparisons, resulting in p-values < 0.0028 were considered statistically significant.

In total, 18 gait parameters were considered for inclusion in two PCA models, i.e. one for each group (MCI, n = 114; and CU, n = 219). A third PCA of cognitively healthy people (n = 143, i.e. excluding those with

Table 1
Participant characteristics.

	Mild cognitive impairment, n = 114[a]	Missing, n	Cognitively unimpaired, n = 219	Missing, n
Age (years), mean (SD)	72.7 (7.2)	–	73.8 (8.1)	–
Sex (female), n (%)	56 (49.1%)	–	122 (55.7%)	–
Education (years), median (q1-q3)	12.0 (9.0–14.3)	1	11.5 (9.0–14.0)	–
Global cognitive functioning (MMSE), median (q1-q3)	27.0 (25.0–28.0)	–	29.0 (28.0–30.0)	–
APOE e4 (yes)[b], n (%)	70 (61.9%)	1	99 (45.6%)	2
Body Mass Index (BMI), mean (SD)	25.6 (3.5)	–	26.7 (3.8)	–
Falls past 12 months (yes), n (%)	35 (31.0%)	1	60 (27.5%)	1
Fear of falling (yes), n (%)	28 (24.6%)	–	56 (25.9%)	3
Depressive symptoms (HADS), median (q1- q3)	3.0 (1.0–5.0)	4	2.0 (1.0–3.0)	9
Comorbidities (yes), n (%)				
Hypertension	36 (31.6%)	–	78 (35.6%)	–
Diabetes	17 (14.9%)	–	25 (11.4%)	–
Ischemic heart disease	11 (9.6%)	–	23 (10.5%)	–
Stroke/ Transient ischemic attack (TIA)	7 (6.1%)	–	7 (3.2%)	–

MMSE=Mini Mental State Examination, 0–30 points, higher=better; HADS=Hospital Anxiety and Depression Scale, depression subscale was used, 0–21 points, higher=worse. a 69% (75 out of 109) had amnestic mild cognitive impairment, i.e., performing worse than − 1.5 z-score on delayed recall from the Alzheimer's Disease Assessment Scale. b Presence of the APOE e4 allele on either of the chromosomes 24, 34, 44, 42 or 43.

Table 2
Descriptions of gait parameters and equations.

Gait parameter	Definition[a]
Step velocity (cm/s)[b]	Step length divided by step time.
Step length (cm)	Measured along the length of the walkway, from heel center of the current footprint to the heel center of the previous footprint on the opposite foot.
Step width (cm)	Distance from heel center of one footprint to the line of progression formed by two footprints of the opposite foot.
Step time (s)	Time elapsed from first contact of one foot to first contact of the opposite foot.
Step swing time (s)	Time elapsed between the last contact of the current footfall to the first contact of the next footfall on the same foot.
Step stance time (s)	Time elapsed between the initial contact (heel contact) and the last contact (toe off) of the same foot.
Double support time (s)	The period when both feet are on the floor simultaneously.
Mean measures are calculated using the equation:	$\text{Mean} = \frac{Average_{Left} + Average_{Right}}{2}$
Variability measures are calculated using the equation:	$\text{Variability} = \sqrt{\frac{(Variance_{Left} + Variance_{Right})}{2}}$
Asymmetry measures[c] are calculated using the equation:	$\text{Asymmetry} = Average_{Left} - Average_{Right}$

[a] Definitions of gait parameters are derived from the GAITRite measurements technical reference (2013); Galna et al., Gait & Posture (2013); and Hollman et al., Gait & Posture (2011).
[b] Calculated using individual step data on step length and step time.
[c] Absolute values are used when presenting asymmetry data.

Table 3
Descriptive data of the 18 gait parameters.

Gait parameter	Mild cognitive impairment, n = 114		Cognitively unimpaired, n = 219		P-values
	Mean (SD)	Min - max	Mean (SD)	Min - max	
Mean measures					
Step velocity (cm/s)	111 (20.9)	57.8–163	120 (15.5)	73.4–159	**< 0.001**[a]
Step length (cm)	61.5 (9.0)	36.4–78.8	64.4 (7.1)	41.6–80.7	0.003[a]
Step width (cm)	9.2 (3.2)	3.2–21.2	8.6 (2.5)	2.6–16.8	0.118[a]
Step time (s)	0.56 (0.05)	0.47–0.73	0.54 (0.04)	0.45–0.67	**0.001**[a]
Step swing time (s)	0.40 (0.03)	0.32–0.51	0.39 (0.03)	0.33–0.46	0.131[a]
Step stance time (s)	0.72 (0.08)	0.57–1.04	0.69 (0.06)	0.52–0.89	**< 0.001**[a]
Double support time (s)	0.32 (0.07)	0.20–0.65	0.30 (0.05)	0.16–0.48	**0.001**[a]
Variability measures					
Step velocity (cm/s)	6.21 (1.96)	3.10–15.1	5.53 (1.75)	2.61–15.0	**0.001**[a]
Step length (cm)	2.65 (0.86)	1.15–5.27	2.25 (0.72)	1.05–7.97	**< 0.001**[a]
Step width (cm)	2.17 (0.56)	1.24–4.52	2.27 (0.58)	1.22–4.69	0.129[a]
Step time (s)	0.020 (0.009)	0.008–0.074	0.016 (0.005)	0.007–0.037	**< 0.001**[b]
Step swing time (s)	0.017 (0.008)	0.007–0.065	0.014 (0.004)	0.007–0.036	**< 0.001**[b]
Step stance time (s)	0.024 (0.011)	0.010–0.070	0.018 (0.007)	0.008–0.056	**< 0.001**[b]
Double support time (s)	0.022 (0.008)	0.010–0.057	0.018 (0.006)	0.007–0.058	**< 0.001**[b]
Asymmetry measures					
Step length (cm)	2.52 (2.39)	0.025–15.4	2.16 (2.13)	0.014–14.2	0.135[b]
Step time (s)	0.017 (0.015)	0.000–0.092	0.012 (0.009)	0.000–0.042	0.028[b]
Step swing time (s)	0.012 (0.012)	0.000–0.079	0.009 (0.008)	0.000–0.043	0.139[b]
Step stance time (s)	0.012 (0.012)	0.000–0.073	0.009 (0.008)	0.000–0.042	0.074[b]

Gait values are non-transformed. Presented p-values are uncorrected; bolded values are significant when using Bonferroni correction (p = 0.0028).
[a] Comparison by using independent-samples t-test.
[b] Comparison by using Mann-Whitney U-test.

SCD from the CU group) was conducted as a sensitivity analysis. Sample sizes of at least 100 have been suggested acceptable when performing PCA [32].

Histograms of the gait parameters were inspected for normality, which was acceptable for most parameters. By log transforming the four temporal gait variability measures and square root transforming the four asymmetry measures, normality of distribution improved. A correlation matrix including all 18 gait parameters was produced for each group. A criterion for inclusion in the upcoming PCAs was correlation ≥ 0.30 (positive or negative) with at least one other gait parameter [33].

Three PCAs were produced (MCI, CU, and one for cognitively healthy people only). Varimax rotation was used for data structure clarification. Scree plots were inspected to decide the number of components to retain [34]. Analyses were rerun twice with a fixed number of components (one additional as well as one less component than suggested by the initial scree plot). This was done to identify the cleanest solution based on three criteria: i) all gait parameters are included in at least one of the components, ii) few cross-loadings (i.e. >±0.32 with more than one component), iii) all components contain at least three gait parameters each [34]. Moreover, the model should explain a substantial part of the total gait variance. Positive or negative loadings of ≥ 0.5 were considered relevant component contributors [34]. The highest loading of each gait parameter was used to determine the component to which each gait parameter belongs. Data was analyzed using IBM SPSS, version 27.

3. Results

3.1. Gait characteristics in people with and without mild cognitive impairment

Those with MCI walked with reduced step velocity as compared to the CU group (111 cm/s vs. 120 cm/s; p < 0.001). Moreover, those with MCI had significantly longer step time, stance time and double support time as compared to CU. All variability measures except step width variability were significantly higher in the MCI group as compared to CU, whereas there were no significant differences regarding asymmetry measures (Table 3).

3.2. Mild cognitive impairment

Of the 18 gait parameters considered for inclusion in the analysis, step width variability was.

excluded in the PCA that addressed people with MCI; due to insufficient correlation with the other gait parameters.

The PCA included 17 gait parameters, and four components were defined that explained 81.0% of the total variance, see Table 4. The

Table 4
Principal component analysis of 17 gait parameters in people with MCI: Item loadings of a 4-component solution, n = 114.

Gait parameter	Variability	Pace/ Stability	Rhythm	Asymmetry
Step velocity variability (cm/s)	**0.899**	-0.225	-0.198	-0.064
Step length variability (cm)	**0.832**	0.217	0.037	-0.082
Step stance time variability (s)[a]	**0.813**	0.233	*0.370*	0.167
Step time variability (s)[a]	**0.747**	0.315	*0.416*	0.209
Double support time variability (s)[a]	**0.734**	0.294	*0.356*	0.156
Step swing time variability (s)[a]	**0.555**	*0.509*	*0.423*	0.250
Mean step length (cm)	-0.293	**-0.813**	-0.103	-0.266
Mean step width (cm)	0.093	**0.719**	-0.024	0.025
Mean step velocity (cm/s)	-0.286	**-0.696**	*-0.494*	-0.289
Step length asymmetry (cm)[b]	-0.022	**0.667**	0.069	0.300
Mean double support time (s)	*0.352*	**0.653**	*0.579*	0.124
Mean step time (s)	0.198	0.186	**0.928**	0.218
Mean step stance time (s)	0.275	*0.409*	**0.828**	0.191
Mean step swing time (s)	-0.072	*-0.449*	**0.801**	0.203
Step stance time asymmetry (s)[b]	0.038	0.152	0.147	**0.915**
Step swing time asymmetry (s)[b]	-0.011	0.194	0.136	**0.908**
Step time asymmetry (s)[b]	0.187	0.217	*0.336*	**0.549**
Variance explained (%)[c]	23.7	21.4	21.1	14.8

Varimax rotation. Bold numbers indicate the highest loading of each gait parameter, which was used to determine the component to which each gait parameter belongs. Italic numbers indicate cross-loadings. MCI= Mild Cognitive Impairment.
[a] Log transformed.
[b] Square root transformed.
[c] Total variance explained: 81.0%.

components were labeled *Variability* (explaining 23.7% of the total variance), *Pace/Stability* (21.4%), *Rhythm* (21.1%) and *Asymmetry* (14.8%). The gait parameters with the highest loading in the respective component were step velocity variability (0.899; *Variability*), mean step length (−0.813; *Pace/Stability*), mean step time (0.928; *Rhythm*) and stance time asymmetry (0.915; *Asymmetry*). All 17 gait parameters had positive or negative loadings ≥ 0.5 in at least one component.

3.3. Cognitively unimpaired

Three out of the 18 gait parameters did not sufficiently correlate with the other parameters and were excluded from the PCA: mean step width, step width variability and step length asymmetry. Hence, 15 gait parameters were included in the PCA in the CU group (Table 5).

The PCA resulted in four components, which we labeled *Variability* (explaining 24.9% of the total variance), *Rhythm* (21.3%), *Pace/Stability* (20.0%) and *Asymmetry* (14.1%). Together, these explained 80.3% of the total variance. The gait parameters with the highest loading in the respective component were step velocity variability (0.895; *Variability*), mean step time (0.972; *Rhythm*), mean step length (−0.908; *Pace/Stability*), and swing time asymmetry (0.891; *Asymmetry*). All 15 gait parameters had positive or negative loadings ≥ 0.5 in at least one component.

Sensitivity analysis included a PCA in cognitively healthy people, i.e. excluding those with SCD from the CU group. This rendered similar results as in the CU group, and four components explaining 75.7% of the total variance; the gait parameters that loaded the highest in each of the four components were the same as in the CU group. The main difference was that swing time variability loaded higher to the Pace/Stability component instead of to the Variability component, as in the CU group. Moreover, step length asymmetry now reached the predefined correlation threshold and was included into the PCA. It did however not load significantly to any component (data shown in Supplementary material).

Table 5
Principal component analysis of 15 gait parameters in cognitively unimpaired people: Item loadings of a 4-component solution, n = 219.

Gait parameter	Variability	Pace/ Stability	Rhythm	Asymmetry
Step velocity variability (cm/s)	**0.895**	-0.192	-0.228	-0.034
Step length variability (cm)	**0.820**	0.036	0.017	-0.023
Step stance time variability (s)[a]	**0.817**	*0.335*	0.165	0.131
Step time variability (s)[a]	**0.773**	*0.418*	0.139	0.080
Double support time variability (s)[a]	**0.751**	*0.343*	0.162	0.106
Step swing time variability (s)[a]	**0.531**	*0.518*	0.290	0.125
Mean step length (cm)	-0.209	**-0.908**	0.192	-0.061
Mean step velocity (cm/s)	-0.190	**-0.870**	*-0.345*	-0.081
Mean double support time (s)	0.141	**0.624**	*0.615*	0.139
Mean step time (s)	0.076	0.198	**0.972**	0.067
Mean step stance time (s)	0.104	*0.392*	**0.885**	0.105
Mean step swing time (s)	-0.019	*-0.324*	**0.847**	-0.033
Step swing time asymmetry (s)[b]	0.090	0.086	0.020	**0.891**
Step stance time asymmetry (s)[b]	0.128	0.072	0.031	**0.878**
Step time asymmetry (s)[b]	-0.051	0.030	0.067	**0.674**
Variance explained (%)[c]	24.9	20.0	21.3	14.1

Varimax rotation. Bold numbers indicate the highest loading of each gait parameter, which was used to determine the component to which each gait parameter belongs. Italic numbers indicate cross-loadings.
a Log transformed.
b Square root transformed.
c Total variance explained: 80.3%.

4. Discussion

This study addresses the limited knowledge of gait components in people with MCI with signs of an incipient neurocognitive disorder, as well as in cognitively unimpaired people. The PCAs resulted in four gait components (*Variability; Pace/Stability; Rhythm; Asymmetry*) in both groups, explaining 81.0% (MCI) and 80.3% (CU) of the total variance. In both groups, the component *Variability* explained the largest variance. Moreover, the same gait parameters had the highest loadings in three of the components: *Variability* (step velocity variability), *Pace/Stability* (mean step length) and *Rhythm* (mean step time). The gait parameters with the highest loadings might serve as core gait variables, i.e. representing the respective component. The component *Pace/Stability* included unique gait parameters in the MCI group, i.e., mean step width and step length asymmetry. That is, although there were similarities in the gait components of the two groups, there were also differences.

4.1. Findings in the MCI group

Step velocity variability was the highest loading gait parameter in the component *Variability*, and all variability measures were in this component. The latter corroborates a previous study in people with MCI [20]. In our study, the component *Variability* explained the largest amount of variance (23.7%) in people with MCI. This finding contrasts the study by Pieruccini-Faria et al. [20], where the variability component explained the least amount of variance. Reasons for this discrepancy could be sample and/or methodological differences. For example, we used steps instead of strides (as steps are considered more reliable variability measures [21]), and we included six variability measures as compared to two [20]. To our knowledge, our PCA study is the first that identified an asymmetry component in people with MCI, and stance time asymmetry had the highest loading.

4.2. Findings in the CU group

In *Variability* (explaining 24.9% of variance), step velocity variability had the highest loading. This is in accordance with the study by Lord et al. [14], which included dementia free older adults. However, other studies identified step/stride length variability as the highest loading parameter [13,15–17]. In our study, step length variability loaded highly on the variability component, signaling its relevance to that component.

Three mean temporal gait measures (step, stance and swing time) loaded highly on *Rhythm*, corroborating prior studies [13–17]. Mean step length and velocity measures were identified as highly relevant parameters of the *Pace/Stability* component, which confirms previous studies [11–17].

Swing time asymmetry had the highest loading in our fourth component; *Asymmetry* (14.1% of the variance). Two prior PCA studies that included asymmetry measures also identified swing asymmetry as highly loading [14,17].

4.3. Similarities and differences between the MCI and CU groups

In both groups, the *Variability*, *Rhythm* and *Asymmetry* components all included the same gait parameters. Moreover, the *Pace/Stability* component contained mean measures of step length, gait speed (i.e. mean step velocity) and DST for both groups. When gait speed and step length decreases, DST increases, contributing to a more stable gait [35,36]. DST can therefore be considered a measure of gait stabilization [35]. According to our results, DST variability clearly belong to the *Variability* component, whereas mean DST loaded highly in both *Pace/Stability* and *Rhythm* indicating a difficulty in categorizing it into one of these components.

It is worth noting that the two PCAs did not include identical gait parameters (due to correlations between parameters <±0.30). The PCA

in the MCI group included 17 gait parameters versus 15 in the CU group. Mean step width and step length asymmetry were included in *Pace/Stability* component in the MCI group, while these parameters were excluded from the PCA in the CU group. The latter is in line with the study by Bernstein et al., where step length asymmetry did not load significantly to any component in cognitively healthy older adults during single task walking [17]. Although mean step width did not reach the inclusion criteria in the cognitively unimpaired group, it may still be a clinical relevant variable as it is considered linked to postural control and stability of gait [37]. Moreover, an increased step width is also associated with several diagnoses such as normal pressure hydrocephalus [38,39] and multiple sclerosis [40]. Step width variability was not included in any of the two PCAs in our study. However, extreme values (high or low) of step width variability have been associated with a history of falling, which suggests that this variable may be of importance if targeting gait in relation to falls [41].

The highest loading gait parameter was the same for both groups in three of the components. This did not apply for the fourth component (*Asymmetry*), where stance time asymmetry loaded highest in the MCI group and swing time asymmetry in the CU group. However, both parameters loaded highly in both groups. Agreement in degree of loadings in the identified components in both groups could indicate that similar gait parameters are important for explaining gait in people with and without MCI.

4.4. Clinical implications and future perspectives

Gait variability measures have been suggested to be sensitive markers for cognitive decline [6,7]; they have been associated with cognitive impairment in general [8,16,42] and with MCI specifically [18,19]. Within-person gait variability is often subtle and difficult to measure with standard clinical equipment. It can however be measured objectively using more advanced technology; this speaks in favor of using objective and more detailed gait measurements than is usually used in a clinical setting. Several gait components, such as *Variability* in neurodegenerative disorders [42] and *Rhythm* and *Pace* in older adults [16], have been associated with cognitive decline. *Rhythm* and *Postural control* have been associated with MCI [42].

This study may aid the identification of gait variables believed to represent different aspects of gait. Gait parameters such as step velocity variability, mean step length, mean step time as well as swing and stance time asymmetry could serve as interesting core variables of different components of gait, for future clinical research in people with and without MCI. However, the selection of gait variables depends on the purpose. Importantly, specific objective spatiotemporal gait characteristics have been associated with dementia types up to 3 years before diagnosis [43].

Although this study focuses on gait as a single task, it needs to be noted that using the dual task paradigm that addresses cognitive-motor interference may be of more diagnostic and prognostic value [43–45]. People with MCI have larger motor dual task costs than healthy controls [45], which is associated with an increased risk of progression to dementia [46]. Increased levels of p-tau have also been shown to be independently associated with worse mobility while dual tasking (mobility + subtraction task) in people with MCI; this was not the case for people who were cognitively unimpaired [47]. In the future, it would be interesting to also investigate gait components while dual tasking.

4.5. Limitations

People with SCD were pooled into the CU group, as previously recommended [29]. The vast majority of those with SCD do not convert to MCI, but they have an increased risk of doing so [28]. We therefore conducted sensitivity analyses that only included cognitively healthy, i.e. SCD were excluded from the CU group; this yielded similar results. An alternative could have been to analyze those with SCD separately, but the sample size (n = 76) was too small for such analysis. Importantly, the motor cognitive risk syndrome (i.e. a combination of slow gait speed and subjective cognitive complaints) induces a greater risk of cognitive decline and dementia compared to the two factors alone [48]. Regarding gait width, both shorter and wider stride is associated with people with MCI when compared to cognitively healthy people, highlighting the importance of such a gait parameter as a discriminatory variable [19].

5. Conclusions

In this cross-sectional study, four components of gait were defined in both the MCI and CU groups, i.e., *Variability*, *Pace/Stability*, *Rhythm* and *Asymmetry*, explaining approximately 80% of the total gait variance. In both groups, *Variability* explained the largest amount of variance. To our knowledge, this is the first study to identify an asymmetry component in people with MCI, where stance time asymmetry loaded highest. In the cognitively unimpaired people, swing time asymmetry loaded the highest. The highest loading gait parameter in each component was the same for both groups in the other three components (step velocity variability, mean step length, and mean step time). These findings suggest core gait variables that could be used in future research if one wishes to cover different components of gait in people with MCI (with signs of an incipient neurocognitive disorder) and cognitively unimpaired people.

Authors' contributions

M.L-R, S.B.J and M.H.N conceived the idea for the paper. M.L-R, S.B.J, OH, N.C.M, E.S and S.P. contributed to data acquisition. M.L-R, S.B.J and M.H.N analyzed the data and wrote the first draft of the article. S.U. provided advice regarding data analysis and interpretation. All authors provided scientific input and revised the paper. All authors approved the final version of the manuscript.

Declaration of competing interest

None of the authors has conflicts of interest to declare. S.P. has served on scientific advisory boards and/or given lectures in symposia sponsored by F. Hoffmann-La Roche, Biogen, and Geras Solutions. O.H. has acquired research support (for the institution) from AVID Radiopharmaceuticals, Biogen, Eli Lilly, Eisai, GE Healthcare, Pfizer, and Roche. In the past 2 years, he has received consultancy/speaker fees from Alzpath, Biogen, Cerveau and Roche.

Data Availability

All data are archived according to the Swedish Act concerning the Ethical Review of Research Involving Humans to attain confidentiality. Data can be shared with a qualified researcher upon reasonable request for the sole purpose of replicating procedures and results and following approval by the responsible ethical committee.

Acknowledgements

This study was funded by The Swedish Research Council (2017-01541; 2021-00905), Sweden; the Strategic Research Area in neuroscience (MultiPark) at Lund University, Lund, Sweden, and Skåne University Hospital (2020-772), Sweden. SB Jonasson was funded by the Skåne County Council, Sweden. The BioFINDER-2 study was supported by the Swedish Research Council (2016-00906), Sweden; the Knut and Alice Wallenberg foundation (2017-0383), Sweden; the Marianne and Marcus Wallenberg foundation (2015.0125), Sweden; the Strategic Research Area MultiPark (Multidisciplinary Research in Parkinson's disease) at Lund University, Sweden; the Swedish Alzheimer Foundation (AF-939932), Sweden; the Swedish Brain Foundation (FO2019-0326), Sweden; The Parkinson foundation of Sweden (1280/20); the Skåne

University Hospital Foundation (2020-O000028), Sweden; Regionalt Forskningsstöd (2020-0314) and the Swedish Federal Government under the ALF agreement (2018-Projekt0279), Sweden.

None of the funding bodies were involved in designing the study, collection, analyses or interpretation of data, or writing of the manuscript.

This study was conducted within the contexts of MultiPark and the Centre for Ageing and Supportive Environments (CASE) at Lund University.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2022.01.012.

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