Human Movement Science 75 (2021) 102720

Contents lists available at ScienceDirect

Human Movement Science

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

Full Length Article

Effects of dichotic listening on gait domains of healthy older adults during dual-tasking: An exploratory observational study

Susana A. Castro-Chavira, Marta M. Gorecka, Olena Vasylenko,
Claudia Rodríguez-Aranda *

Department of Psychology, University of Tromsø, The Arctic University of Norway; Tromsø, Norway

ARTICLE INFO

Keywords:
Over-ground walking
Multi-tasking
Factor structure
Principal component analysis

ABSTRACT

Background: Identification of the cognitive mechanisms behind gait changes in aging is a prime endeavor in gerontology and geriatrics. For this reason, we have implemented a new dual-task paradigm where an auditory attentional task is performed during over-ground walking. Dichotic listening assesses spontaneous attention and voluntary attention directed to right and left-ear. The uniqueness of dichotic listening relies on its requirements that vary in difficulty and recruitment of resources from whole brain to one brain hemisphere. When used in dual-tasking, asymmetric effects on certain gait parameters have been reported.
Objectives: The present study aims to acquire a more global understanding on how dichotic listening affects gait domains. Specifically, we aimed to understand how spontaneous vs lateralized auditory attention altered the Principal Component Analysis (PCA) structure of gait in healthy older adults.
Methods: Seventy-eight healthy older adults (mean age: 71.1 years; 44 women and 34 men) underwent the Bergen dichotic listening test while walking. As this study only focuses on the effects of the cognitive task on gait, only dual-task costs for gait were calculated and entered into the PCA analyses. We explored the PCA structure for the effects on bilateral gait parameters (i.e., both limbs together) as well as on lateralized gait parameters (i.e, separate parameters by limb). We first established gait domains during single-task walking. Then, dual-task cost scores for gait were entered in a series of PCAs.
Results: Results from the PCAs for bilateral gait parameters showed limited alterations on gait structure. In contrast, PCAs for lateralized data demonstrated modifications of the gait structure during dichotic listening. The PCAs corresponding for all dichotic listening conditions showed different factor solutions ranging between 4 and 6 factors that explained between 73.8% to 80% of the total variance. As a whole, all conditions had an impact on “pace”, “pace variability” and “base of support variability” domains. In the spontaneous attention condition, a six-factor solution explaining 78.3% of the variance showed asymmetrical disruptions on the PCA structure. When attention was focused to right-ear, a five-factor solution explaining 89% of the variance and similar to baseline was found. When attention was directed to left-ear, a four-factor solution explaining 73.8% of the variance was found with symmetrical impact on all factors.
Conclusions: These findings demonstrate for the first time that specific facets of attentional control affects gait domains both symmetrically and asymmetrically in healthy older adults.

---

* Corresponding author.
E-mail address: claudia.rodriguez-aranda@uit.no (C. Rodríguez-Aranda).

https://doi.org/10.1016/j.humov.2020.102720
Received 23 April 2020; Received in revised form 16 November 2020; Accepted 17 November 2020

1. Introduction

The field of aging dealing with the study on how cognition and gait interact in the older adult has deserved enormous attention in the last decades. The most recurrent method used to understand this interaction is the dual-task paradigm (Muir-Hunter & Wittwer, 2016). This methodology requires a person to perform a cognitive task while walking and decrements either in gait or in performance of the cognitive task are regarded as the result of disrupted attentional abilities, which are greatly deteriorated in aging (Montero-Odasso, Verghese, Beauchet, & Hausdorff, 2012). It is worth mentioning that most often, only the effects of the cognitive task on gait have been explored (e.g. Wollesen, Wanstrath, van Schooten, & Delbaere, 2019), which might be related to the clinical interest in estimating the risk of fall in the older adult (Nordin, Moe-Nilssen, Ramnemark, & Lundin-Olsson, 2010).

Decrements in performance are evaluated in terms of dual-task costs, which are the difference between single and dual-task performance. However, interpretation of the dual-task results is challenging (Holtzer, Wang, & Verghese, 2012). Some theoretical models have been developed to explain the interaction cognition-gait in terms of limited information processing (Pashler, 1994), competing resources (Wickens, 2008) or synergistic interference due to additive use of attentional resources (Eysenck, Derakshan, Santos, & Calvo, 2007). Although, these models provide a valuable framework for interpretation of results in dual-task studies, it is evident that the interference strongly depends on the type of cognitive task applied during walking. In a review by Wollesen et al. (2019) it was reported that the most used cognitive tasks in dual-task studies are arithmetic and verbal fluency, which are considered mental track tests. However, the mentioned cognitive tasks cannot help to unveil how a concrete cognitive mechanism disrupts a specific gait parameter. The reason is that these tasks rely on interrelated high-order cognitive processes, which are too intricate that findings cannot be generalized to everyday situations. Thus, their ecological validity is dubious. An additional drawback in this line of investigation is the general lack of consideration of the role of sensory loss due to aging. For instance, it is widely acknowledged that age-related hearing loss and hearing impairments are related to several cognitive dysfunctions (Loughrey, Kelly, Kelley, Brennan, & Lawlor, 2018). Sensory decline in the hearing system is of particular relevance for dual-task research in aging, since practically all cognitive tasks rely on oral language, either related to tasks' instructions or to the evaluated stimuli. Age-related hearing loss is one of the most prevalent chronic conditions in older adults (Jayakody, Friedland, Martins, & Sohrabi, 2018). About 60% of older persons over 70 years present a degree of hearing loss that has been related to increased risk of falls (Van Eyken, Van Camp, & Van Laer, 2007) and loose of functional status (Wayne & Johnsrude, 2015). Because good integrity of the hearing system is central to balance and gait (Viljanen et al., 2009), our group has implemented a robust test for the assessment of auditory selective attention into the over-ground dual-task paradigm (Gorecka, Vasylenko, Espenes, Waterloo, & Rodríguez-Aranda, 2018), namely the Dichotic Listening task (Hugdahl, 2003).

1.1. Dichotic Listening test

This test is a recognized cognitive task for the study of divided attention in the auditory modality and it varies in difficulty degree. In addition, it assesses lateralized attentional capacities. In the dichotic listening test, simultaneous presentation of different auditory stimuli to the right and the left ear takes place. Stimuli can be simple words, numbers or syllables. Numerous trials are executed and on each trial, presentation of stimuli is congruent or incongruent to both ears. Specifically, the dichotic listening task consists of three conditions where participants are required to verbally report: 1) the best perceived stimuli regardless of ear, 2) stimuli from right ear, and 3) stimuli from left ear. These three conditions respectively measure spontaneous attention and voluntary control of attention to right or left ear. Due to the anatomical decussation of the auditory system, stimuli from right ear is processed in the left hemisphere, which for right-handed persons is the area specialized for language (Corballis, Badzakova-Trajkov, & Haberling, 2012). Stimuli coming from left-ear is transmitted to the right-hemisphere first and then, to the left-hemisphere via corpus callous for final processing (Westerhausen & Hugdahl, 2008). Thus, right-handed persons report easily and faster stimuli from right ear, which is a phenomenon known as "the right-ear advantage". In dichotic listening, the first condition called Non-Forced, assesses spontaneous focus of attention where subjects are asked to report whichever stimuli they hear best. The Non-Forced condition is proposed to be relatively effortless for right-handed individuals as it relies on "bottom-up" or stimulus driven responses (Hugdahl, 2016). The second condition, called Forced-Right is relatively easy for right-handers though, it imposes higher cognitive demands than the Non-Forced condition as subjects need to direct their attention voluntarily to the dominant right-ear. Finally, during the third condition called Forced-Left, subjects are asked to attend their non-dominant ear (i.e, left ear), which entails a conflicting situation since they need to suppress their natural preference to attend the right-ear and enhance their attentional abilities to select stimuli from the left side. For this reason, the Forced-Left condition is considered the most difficult one as it demands involvement of executive functions (Andersson, Reinvang, Wehling, Hugdahl, & Lundervold, 2008). This assertion is particularly true for older adults (Hommet et al., 2010), who experience a normal age-related decline on executive abilities (Buitenweg, Murre, & Ridderinkhof, 2012). Notwithstanding, both Forced-Right and Forced-Left conditions are regarded as demanding situations because they are based on "top-down processes" or volitional processes guided by instructions. In sum, the three dichotic listening conditions require various degrees of effort and cognitive demands that increase gradually from Non-Forced to Forced-Left conditions (Hugdahl et al., 2009).

Dichotic listening is not only a well-known task at the behavioral level, but its underlying neural mechanisms have been largely explored (e.g., Hirnstein, Hugdahl, & Hausmann, 2014; Hugdahl, 2011; Passow, Westerhausen, Hugdahl, Wartenburger, & Heekeren, 2014). Due to the above-mentioned qualities of dichotic listening, we consider this task particularly convenient for the study of gait in dual-tasking as it resembles the everyday situation of walking, listening and talking, which makes dichotic listening an ecologically valid tool from which findings can be extrapolated to daily situations.

1.2. Lateralized effects on gait due to execution of dichotic listening

Due to the nature of the stimuli employed in dichotic listening, it is possible to evaluate the ability to focus attention in a "lateralized" way to either the dominant or the non-dominant ear. This particularity of dichotic listening allows to measure lateralized effects of cognition on gait. Since dichotic listening demands the recruitment of attentional abilities to right or left side in the conditions of forced directed attention, a cortical activation on right or left-hemispheres occurs, which is superimposed to the activation of motor programmes controlling gait movements on both sides of the body. Our initial assumption was that in such a scenario, performance of dichotic listening during walking would disrupt asymmetrically the coordination of the gait motor programs.

Indeed, we corroborated this assumption as we found lateralized effects of dichotic listening on various independent gait parameters of seventy-eight right-handed older adults who executed the dual-task paradigm during over-ground walking (Gorecka et al., 2018). The asymmetric effects were moderated by degree of hearing loss. Results demonstrated significant differences on specific raw gait parameters between left and right limbs. Mostly, the right foot showed asymmetric differences on stride length variability on all dichotic listening conditions as well as increased step width on the Forced-Left condition. The left foot was also affected asymmetrically on regards to gait speed, which decreased significantly during the Non-Forced condition. Also, we found that when subjects were asked to attend to left ear but instead they report right-ear stimuli, their gait variability decreased, which according to the literature is a sign for the maintenance of balance (Hausdorff, Rios, & Edelberg, 2001). In contrast, when subjects reported correctly left-ear answers, their variability in restricted gait outcomes increased, which suggests that attending the non-dominant ear increases the risk of falling (Verghese, Holtzer, Lipton, & Wang, 2009). In sum, forcing attention to the left-ear causes a deleterious effect on gait, while ignoring left-ear stimuli reduces gait variability and assures gait features related to a safe walk. Previously, only another study had applied the Dichotic Listening task in a dual-task experiment, though, during walking on a treadmill with young and older participants (Decker et al., 2017). Thus, our study from 2018 (Gorecka et al., 2018) is the first one showing laterality effects on gait measures of older adults due to execution of dichotic listening during over-ground walking. Currently, another study from our group has further corroborated asymmetric effects due to this dual-task paradigm, in healthy younger adults (Gorecka, Vasylenko, & Rodríguez-Aranda, 2020).

1.3. The present study

Despite the noteworthy lateralized findings in older adults, it is desirable to understand the effects of the dichotic listening task not only on individual gait parameters, but on coordinated gait measurements that allow to appraise which are the gait domains more prone to be disturbed due to the cognitive demands of dichotic listening. Thus, even though the analysis of many isolated gait parameters is a regular practice and an adequate initial approach to observe effects of dual-tasking, this strategy overlooks the fact that gait measures are highly correlated. For this reason, several studies have applied Principal Components Analysis (PCA) to gait data (Hollman, Mcdade, & Petersen, 2011; Lord et al., 2013; Verghese, Wang, Lipton, Holtzer, & Xue, 2007; Verlinden et al., 2013). In some studies, the use of PCA aims to reduce the number of variables and hence, avoid multi-collinearity issues (Jolliffe & Cadima, 2016). In other studies, PCA is applied to find structured dimensions representing gait areas that can be evaluated in relationship to treatments or to specific conditions, such as diseases or lesions (e.g., Federolf, Boyer, & Andriacchi, 2013).

In the present study, we aim to re-evaluate the data acquired on our study from 2018 to understand whether specific dimensions of gait are more susceptible to the effects of any of the dichotic listening conditions. As we aim to explore how the gait structure of older adults is altered by the dual-task paradigm, we only focus on the effects of dichotic listening on gait. Although, it is relevant to appraise in which way the dual-task paradigm affects the cognitive outcomes, analysis of the effects on the cognitive task is out of the scope of the present study. The effects of dichotic listening are reflected as dual-task cost scores (DTCs), and therefore, we entered the DTCs into the analyses. Thus, higher loadings (i.e. ≥ 0.7; Tabachnick & Fidell, 2007) on an obtained factor will reflect that gait changes are highly associated to a given domain.

In sum, our first goal is to explore the PCA structure of data coming from bilateral gait outcomes. As a second goal, we aimed to unveil whether dichotic listening during dual-tasking alters any gait domain asymmetrically. For this reason, we applied PCA techniques on the lateralized DTCs of gait during the three dichotic listening dual-task conditions. By doing so, we will gain a broader insight into how sustained attention vs. voluntary directed attention to the right or left sides alter or not particular domains of gait asymmetrically in healthy older adults. To the best of our knowledge, this is the first investigation aiming to explore possible effects of a lateralized cognitive task with various difficulty levels on the PCA structure of gait. Due to the exploratory nature of this investigation, no hypotheses can be proposed. Nevertheless, based on the dichotic listening literature, we intuitively consider that possible changes on gait structures, including asymmetric effects, might arise in the conditions where volitional focus of attention is required, that is in the Forced-Right and in the Forced-Left conditions.

2. Method

2.1. Participants

The data set employed in the present study stems from the same group of participants included in Gorecka et al., 2018. The participants were 78 healthy, right-handed older adults with a mean age of 71.1 years and standard deviation (SD) of 6.8 years. Forty-four of them were women, who represented 56.4% of the sample. The mean educational attainment of the sample was 13.1 years with an SD of 4 years. The demographic and cognitive characteristics of the sample are shown in Table 1.

Participants included in the study did not present any physical or neurological disease and were cognitively normal and without depression. The Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was used to assess cognitive status. The Beck Depression Inventory (BDI-II; Beck, Steer, & Brown, 1996) was used to rule out depression. The 36-item Healthy Survey (SF-36; Loge, Kaasa, Hjermstad, & Kvien, 1998) was used to evaluate physical health. Pure tone audiometry was measured and used to rule out hearing impairment (Madsen Itera II, GN Otometrics, Denmark). The Briggs and Nebes modified version of Annett's Handedness Inventory (Briggs & Nebes, 1975) and Waterloo Footedness Inventory-Revised (Elias, Bryden, & Bulman-Fleming, 1998) were used to assure inclusion of right-handed participants. None of the participants scored within the ranges for left-handedness (−9 to −24) or left-footedness (−11 to −20). Following standard criteria, a cut-off of ≥9 on the handedness inventory was used to designate right-handers (Lezak, 1995) and all the participants scored within this rule. The corresponding score for designation of right- footedness was ≥11 (Paquet, Taillon-Hobson, & Lajoie, 2014). We need to highlight that 35 subjects had scores ranging from −6 to 10 in the Waterloo Footedness Inventory-Revised, which suggests a mixed foot preference (Paquet et al., 2014). Because these individuals presented scores in the Briggs and Nebes inventory suggesting right-handedness (scores ranging between 9 and 24), we decided to retain all the participants for the analyses. The rest of the participants (i.e., 43 subjects) had scores in the footedness inventory ranging from 11 to 20, which designates right-footedness.

As this study is part of a larger project, all participants were additionally tested with a comprehensive neuropsychological battery that allowed to obtain a cognitive profile of different cognitive domains. Results from the neuropsychological battery can be consulted in Gorecka et al. (2018).

Inclusion criteria were: > 60 years of age, be right-handed, normal or corrected normal vision and hearing, no diagnosis of orthopedic, motor or other co-morbidities likely to impact gait as verified by medical history, be native Norwegian speakers due to the cognitive demands of the cognitive tests, cut-off criteria on MMSE >28 and cut-off criteria on BDI-II < 19. Exclusion criteria comprised pathology that directly affects the musculoskeletal system such as rheumatoid arthritis, neuropathy or myopathy, vertigo, joint replacement, recent surgery, acute illness, or a history of pulmonary, cardiac, or locomotor disorders. Exclusion criteria due to hearing loss were interaural asymmetry between ears of more than 15 dB, and > 45 dB averaged pure-tone threshold for each ear. Exclusion criteria also comprised having a medical condition interfering with cognitive test performance or having scores below/above the cut-off criteria for designating mental impairment and depression.

Being this study part of a major investigation where healthy young and older controls as well as dementia patients were assessed, the samples sizes were calculated correspondently with a power of 95% and a significance level of 5%. Thus, 66 persons were deemed necessary. In order to avoid problems of attrition, the sample size was augmented by about 20% to 78 persons. In the present study, a data exploratory technique is the main analysis, and for this technique there are no established criteria to stipulate the sample size (Shaukat, Rao, & Khan, 2016). For instance, application of PCA to assess gait properties has been successfully conducted on very small-sample sizes (e.g., Federolf et al., 2013). Though, the number of participants employed in this study ($n = 78$) agrees with similar studies conducting PCA on spatiotemporal gait data (e.g., Guffey, Regier, Mancinelli, & Pergami, 2016). The Research Ethics Committee (Project Number 2009/1427 REK sør-øst A) approved the study and all participants provided signed, informed consent prior to participation in the study.

2.2. Gait assessment

Acquisition of spatio-temporal parameters of gait was conducted with the Optogait System (Optogait, Microgate, Bolzano, Italy), which quantifies gait parameters via photoelectric cells that register interference in light signals. The system is built upon a series of

Table 1
Demographics and background information.

	Mean (SD)
Age (years)	71.1 (6.8)
Women, n (%)	44 (56.4)
Education (years)	13.1 (4.0)
MMSE score	28.7 (1.9)
BDI II score	5.6 (5)
Height (cm.)	169.31 (8.1)
Body Mass Index	27.0 (4.3)
SF-36 RAND	105.1 (7.4)
Grip strength (kg.)	34.7 (10.4)
Pure tone audiometry – best score (dB)	22.0 (10.6)
Handedness	20.3 (4.6)
Footedness	11.5 (6.8)
Gait distance baseline (meters/1 min.)	68.1 (10.8)
Gait distance dual-task NF condition (meters/3 min.)	188.6 (37.6)
Gait distance dual-task FR condition (meters/3 min.)	177.2 (40.8)
Gait distance dual-task FL condition (meters/3 min.)	178.7 (41.7)

Note: MMSE = Mini-Mental State Examination; BDI-II = Beck depression inventory II; SF-36 = 36-Item Short Form Survey Instrument; NF = Non-Forced condition; FR = Forced-Right condition, FL = Forced-Left condition.

transmitting-receiving bars with LED diodes position on each bar 1 cm apart, 3 mm above the ground that need to be located parallel to each other. The bars in our study created a 7 m long x 1.3 m wide rectangular corridor where participants walk in loops counter-clockwise. Optogait measures contact times with an accuracy of 1 thousandth of a second and the position of the interrupted LEDs with a space resolution of 1.041 cm. Studies on the reliability of Optogait suggest that this system can be used with confidence to assess spatio-temporal parameters in experimental and clinical settings (Bernal, Becerro-de-Bengoa-Vallejo, & Losa-Iglesias, 2016; Carbajales-Lopez et al., 2020; Lienhard, Schneider, & Maffiuletti, 2013). Data were extracted at 1000 Hz and saved on a PC using the OptoGait Version 1.6.4.0 software. Gait parameters examined were gait speed, step length, stride length and step width, for both feet (i.e., bilateral) and by foot. The Mean (M) and coefficient of variation (CoV) were calculated for each parameter during single-walking and during the dual-task conditions (see section *2.4 Procedure*).

2.2.1. Calculation of dual-task costs (DTCs)

Results of the gait parameters obtained from single walking provided the baseline scores, which were used in the calculation of the dual-task cost scores (DTCs). DTCs were calculated by determining the difference between gait parameters in single walking and gait parameters during dual-tasking. The calculated scores were: Baseline gait scores *minus* Non-Forced gait scores (DTCsNF), Baseline gait scores *minus* Forced-Right gait scores (DTCsFR), and Baseline gait scores *minus* Forced-Left gait scores (DTCsFL).

2.3. Dichotic listening

The Bergen dichotic listening test (Hugdahl, 1995) adapted to the *E*-Prime software was used. The test consists on the simultaneous presentation of six syllables (BA, DA, GA, KA, PA, TA) spoken by a male voice during three minutes. Two identical syllables presented at the same time, homonyms, are included as perceptual control measures. There are 36 trials in each condition. Thus, a maximum correct score is 30 (excluding the 6 homonyms). The duration of presentation of the syllables is of 4000 milliseconds. The stimuli are presented through noise cancelling headphones and subjects are asked to loudly report their answers at each time of stimuli presentation. Responses were recorded with a digital voice recorder hanging around the participants' neck. E-prime 2.0 Software (Psychology Software Tools, Inc., Pittsburgh, PA, USA) was used to present the stimuli. The dichotic listening task imposes three different conditions. On the first one, participants are asked to report the clearest sound they perceived (Non-forced condition, NF). This part allows the experimenters to settle if subjects attend more to stimuli coming from the right or the left side. On the second condition,

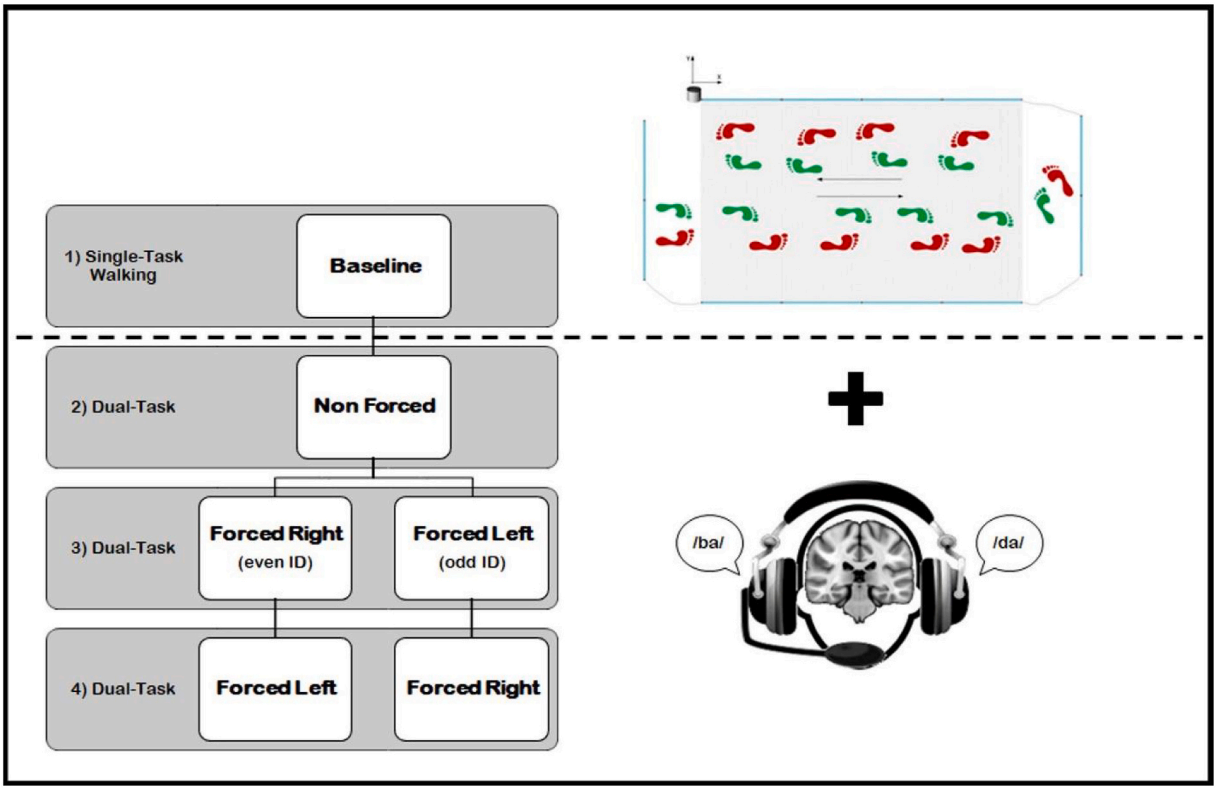

Fig. 1. Experimental layout. The participants underwent the experimental situation in four stages: 1) single-task only walking, 2) spontaneous attentional condition (Non-Forced) in dual-task, 3) & 4) volitional attentional conditions to either right ear (Forced-Rigth) or left ear (Forced-Left). For 3) & 4), participants with even ID numbers performed the Forced-Right condition first, while participants with odd ID numbers performed the Forced-Left condition first.

participants are instructed to report only stimuli presented to the right ear and neglect stimuli listen on the left ear (Forced-Right condition, FR). Finally, the third condition requires subjects to report stimuli from the left ear while neglecting stimuli from right ear (Forced-Left condition, FL). Each condition lasts for three minutes. The scoring of answers is based on the number of correctly reproduced syllables presented to the right, or left ear respectively. Because it is necessary to settle the participant's ear preference for reporting of stimuli, the Non-Forced condition is always executed first. However, the directed attention conditions, Forced-Right and Forced-Left are presented counterbalanced across subjects depending on the participants' ID number (see Fig. 1).

2.4. Procedure

At the beginning of the test session participants provided written informed consent and they obtained thorough information of the study. An initial interview was carried out followed by the neuropsychological test battery, questionnaires and the audiometry test. Afterwards, participants continued with the dual-task paradigm. After acquisition of height and weight of all participants, subjects were required to walk at a self-selected pace into the Optogait area. An experimenter demonstrated how to walk counter-clockwise before the participants executed a trial. The Optogait system started recording gait as the subject took the first footstep, initiated by a verbal signal of the experimenter. In the baseline condition, participants were asked to walk for one minute within the corridor. This condition was deemed to be shorter than the dual-task conditions based on a pilot trial where some older participants reported dizziness and tiredness by walking during 3 min without the concomitant task. However, for the dual-tasking, 3 min were allotted for each dichotic listening condition in order to match the standard time required for the task. Prior to dual-task conditions, participants were given a demonstration trial of the experimental procedure. Also, participants were required to listen and respond to three CV-presentations while wearing headphones without walking, to ensure comprehension of the instructions. Participants were given sufficient time to understand instructions and adjust the volume until reporting clear perception of the dichotic listening stimuli.

Next, for dual-tasking subjects were given the following instructions: "We ask you to say loudly the syllables that you perceived a) the clearest (in Non-forced condition), b) from right-ear (in Forced-Right condition), c) from left-ear (in Forced-Left condition), while you walk in rounds in the designated area as previously demonstrated. Please keep walking and reporting loudly the syllables during the entire trial as well as you can". Equal task prioritization was required. The dichotic stimuli was initiated simultaneously as the subject lifted a foot to initiate walking, again when the experimenter gave a verbal cue. Short breaks were given between conditions. The oral responses were recorded and written down by one experimenter. Afterwards, the recorded responses were listened and manually inserted in the *E*-prime software by a second experimenter, which ensure reliable data.

Fig. 1 shows the experimental flow of the consecutive test series and layout.

2.5. Statistical analyses

All statistical analyses were performed using the SPSS 25 software. A MANOVA was used to compare the gait measures between limbs during over-ground, baseline walking.

2.5.1. Principal component analysis (PCA)

In order to understand how dichotic listening affects gait dimensions across the three attentional conditions it was deemed necessary to use the DTCs in the PCA analyses as they indicate the change on gait relative to single-task walking. Thus, three independent PCAs with varimax rotation with Kaiser normalization were performed for each dual-task condition. The Kaiser-Meyer-Olkin statistic was used to ensure sampling adequacy (KMO measures larger than 0.5). In this way, we obtained and selected orthogonal factors using standard selection criteria of scree plot and eigenvalues $\geq$1. Selection of variables contributing to any factor required loading values to be $\geq$0.5. In order to establish gait domains in our sample, we performed an initial PCA on the gait data from the baseline condition. Following customary procedures, we first conducted a set of PCA analyses on the bilateral measures (i.e., mean values of gait parameters from both limbs). Thereafter, we performed PCAs on the lateralized DTCs. Since our previous findings

Table 2
Over-ground walking measures at baseline.

Measure	Right foot M (SD)	Left foot M (SD)	MANOVA F	Partialη^2
MEAN				
Gait speed (m/s)	1.14 (0.18)	1.14 (0.18)	0.089	0.001
Step length (cm)	63.70 (10.54)	64.54 (7.65)	0.898	0.012
Stride length (cm)	131.15 (15.75)	131.32 (15.78)	0.062	0.001
Step width (cm)	9.12 (3.02)	8.35 (2.79)	**8.200****	0.096
CoV (%)				
Gait speed	5.63 (5.30)	5.17 (4.44)	1.625	0.021
Step length	5.49 (3.44)	5.25 (3.44)	0.448	0.006
Stride length	7.31 (7.77)	6.91 (7.96)	0.106	0.001
Step width	79.06 (42.15)	79.34 (41.62)	0.003	0.000

Note. M, mean; SD, standard deviation; CoV, coefficient of variation calculated with the formula [SD/Mean] x 100%. ** $p < 0.01$. Significant *F* in bold figures. $\alpha = 0.05$.

demonstrated asymmetric effects on gait, it was important to explore whether gait domains presented lateralized loadings under certain dichotic listening conditions.

3. Results

3.1. Gait assessment for baseline

Raw data for gait parameters during single walking (baseline) are shown in Table 2. These data demonstrate that only step width M had significantly asymmetric values. Differences for DTC outcomes by condition for bilateral gait parameters and lateralized by limb are presented as Supplementary Material (see Supplementary Table 1).

3.2. PCAs for bilateral gait parameters

Separate PCAs were conducted initially for the bilateral gait parameters. The baseline condition showed three factors that correspond to the domains of "pace", "pace variability" and "base of support variability". The same three-factor solution was found for the Non-Forced condition, while only the two first factors appeared in the Forced-Right and Forced-Left conditions. A particularity in this data was that despite similar PCA structures across conditions, the solutions related to dichotic listening only explained a limited percentage of the total variance ranging from 63.6% in Forced-Left to 67.7% in Non-Forced. Only the baseline condition explained a percentage above 70% of the total variance (75.7%). Results from the bilateral parameters are shown in the Supplementary Material (see Supplementary Tables 2–5).

3.2.1. PCA for lateralized gait parameters in baseline

Results from the PCA during single-walking yielded five factors that accounted for 80.3% of the variance (Table 3). We obtained a five-factor solution, where the first factor explained 32.1% of the variance and showed loadings over 0.5 in left and right Ms. of gait speed, step length and stride length. Thus, in accordance with literature in the field, this factor corresponds to "pace". The second factor explained 21.8% of the variance and captured high loadings from left and right sides for CoVs of gait speed and step length. For this reason, the second factor corresponds to "pace variability". The third factor enclosed the Ms. of step width, while CoV values of the same measure presented higher loadings on the fourth factor. For these reasons, we named respectively these factors "base of support" and "variability of gait of support". Each of the latter factors explained correspondently 10.9% and 8.9% of the variance and both had high loadings in left and right step width scores. The last factor explained 6.6% of the variance and it comprised exclusively loadings from stride length CoV. For this reason, we labeled this factor "stability".

3.2.2. Gait domains across dichotic listening conditions in dual tasking

3.2.2.1. Non-forced condition. This analysis yielded six factors that accounted for 78.6% of the variance (see Table 4). The first factor (NF-PC1) contributed with 24% and it showed high loadings from right and left limbs for DTCs-M gait speed, step length, and stride length. Thus, this factor equals the pace factor obtained for baseline. The next factor (NF-PC2) explained 15.7% of the variance and it

Table 3
Factor loadings of DTCs gait parameters during Baseline by limb.

	Limb	Factors				
		Pace	Pace Variability	Base of Support	Base of Support Variability	Stability
Gait Speed M	R	**0.927**	−0.084	−0.124	−0.063	0.013
	L	**0.922**	−0.099	−0.108	−0.050	0.012
Step Length M	R	**0.725**	−0.112	0.266	0.082	0.042
	L	**0.956**	−0.163	−0.031	−0.024	0.045
Stride Length M	R	**0.958**	−0.123	−0.045	0.036	−0.144
	L	**0.954**	−0.098	−0.036	0.042	0.193
Gait Speed CoV	R	−0.100	**0.852**	0.219	0.089	−0.031
	L	−0.128	**0.893**	0.036	−0.021	0.049
Step Length CoV	R	−0.274	**0.840**	0.154	0.018	0.021
	L	−0.089	**0.877**	0.018	0.033	−0.044
Stride Length CoV	R	0.050	0.369	0.090	0.213	**−0.612**
	L	0.116	0.208	0.029	0.190	**0.757**
Step Width M	R	0.010	0.067	**0.956**	0.033	0.056
	L	−0.086	0.388	**0.763**	−0.112	−0.132
Step Width CoV	R	0.112	0.251	−0.222	**0.753**	0.112
	L	−0.100	−0.123	0.128	**0.860**	−0.051
Variance Explained (%): 80.3		**32.1**	**21.8**	**10.9**	**8.9**	**6.6**

Note. Factors extracted by principal component analysis and rotated by varimax with Kaiser normalization. Loadings larger than ±0.5 are shown in bold type. M, mean; CoV, coefficient of variation calculated with the formula [SD/Mean] x 100%; R, right limb; L, left limb.

roughly corresponds to the second factor from baseline called “pace variability”. NF-PC2 comprised higher loadings from right and left limbs for gait speed DTCs-CoVs and for the left step length DTCs-CoVs. The next factor (NF-PC3), showed relevant loadings for DTCs-Ms regarding gait speed, step length and step width and they explained 11.4% of variance. Of importance is that these significant loadings came only from the right limb.

The fourth factor (NF-PC4) explained 9.9% of variance and it showed main loadings from stride length DTCs-M and DTCs-CoV scores of the right limb. The fifth factor (NF-PC5) explained 9.3% of variance and comprised right and left step width DTCs-CoVs, which would match the “base of support” factor in baseline. Finally, the sixth factor (NF-PC6) explained 8.3% of the variance and it displayed relevant loadings from the left limb regarding stride length DTCs-CoV and step-width DTCs-M.

3.2.2.2. Forced-right condition. Results from this analysis yielded five factors that accounted for 80% of the variance. As it can be noticed in Table 5, this factor solution corresponds in its totality to the baseline solution. The only difference relies on slightly lower loadings for the first 3 factors and increased loadings on the “stability” domain. In addition, there was a variation on the percentages of the variance explained by each factor: 26.8% for pace (FR-PC1), 19% for pace variability (FR-PC2), 15.2% for base of support (FR-PC3), 9.5% for base of support variability (FR-PC4) and 9.5% for stability (FR-PC5).

3.2.2.3. Forced-left condition. The PCA analysis for this condition showed a four-factor solution, that accounted for a total of 73.8% of the variance (see Table 6). In this condition, only the first (FL-PC1) and the fourth (FL-PC4) factors matched the “pace” and “base of support variability” domains observed in baseline. FL-PC1 explained 28.2% of the variance while FL-PC4 accounted only for 9.9%. The second factor (FL-PC2) showed high loadings from gait speed DTCs-CoVs and step width DTCs-Ms from both limbs. The third factor (FL-PC3) assembled bilateral DTCs-CoVs from all gait variables, except for step width.

4. Discussion

4.1. PCA structures of bilateral gait outcomes under baseline and dichotic listening

The first goal of this study was to understand which gait domains in older adults were prone to alterations due to dichotic listening performance in dual-tasking. Yet, before addressing this question it is important to highlight that results from our PCA during single-walking (i.e., baseline) converged with findings from earlier reports including the same variables (Hollman et al., 2011; Lord et al., 2013; Verghese et al., 2007; Verlinden et al., 2013). This is an important aspect of our investigation, as the baseline PCA solution allowed us to establish the actual gait domains in our sample. However, PCA solutions of the bilateral gait outcomes during dual-tasking were not entirely conclusive as they only explained a reduced part of the variance ranging between 63.6% to 67.7%. Thus, it is an open question whether we can rely on these factor solutions since the cumulative percent of variance accounted for is rather low. According to standard practice, PCAs accounting for at least 70% of the total variance should be regarded as valid and can be retained for further interpretation (Jolliffe & Cadima, 2016). Compellingly, the lateralized PCA structures described in the next section portray more robust factor solutions.

Table 4
Factor loadings of gait dual task costs per limb for the Non-forced condition.

	Limb	Factors					
		NF-PC1	NF-PC2	NF-PC3	NF-PC4	NF-PC5	NF-PC6
Gait Speed M	R	**0.605**	−0.099	**−0.604**	−0.009	0.187	0.150
	L	**0.876**	−0.200	−0.034	−0.167	0.082	0.001
Step Length M	R	**0.627**	−0.034	**0.469**	0.002	−0.041	0.061
	L	**0.919**	−0.123	0.084	0.012	−0.003	−0.168
Stride Length M	R	**0.683**	−0.163	0.026	**0.657**	0.080	−0.085
	L	**0.884**	0.032	−0.210	0.111	0.095	0.162
Gait Speed CoV	R	−0.079	**0.904**	0.129	0.042	0.022	−0.018
	L	−0.041	**0.845**	0.113	−0.052	0.122	−0.004
Step Length CoV	R	−0.357	0.441	−0.233	0.082	−0.386	0.330
	L	−0.162	**0.780**	−0.193	−0.023	0.057	0.198
Stride Length CoV	R	−0.113	0.004	−0.088	**0.960**	0.025	0.016
	L	0.146	0.237	−0.409	0.382	0.082	**0.504**
Step Width M	R	0.051	0.064	**0.879**	−0.097	−0.092	0.271
	L	−0.016	0.058	0.306	−0.070	0.050	**0.831**
Step Width CoV	R	−0.037	0.102	−0.161	0.136	**0.774**	−0.125
	L	0.157	0.079	−0.021	−0.065	**0.803**	0.238
Variance Explained (%): 78.6		**24.0**	**15.7**	**11.4**	**9.9**	**9.3**	**8.3**

Note. Factors extracted by principal component analysis and rotated by varimax with Kaiser normalization. Loadings larger than ±0.5 are shown in bold type. M, mean; CoV, coefficient of variation calculated with the formula [SD/Mean] x 100%; R, right limb; L, left limb.

Table 5
Factor loadings of gait dual task costs per limb for the Forced-right condition.

	Limb	Factors				
		FR-PC1	**FR-PC2**	**FR-PC3**	**FR-PC4**	**FR-PC5**
Gait Speed M	R	**0.853**	−0.180	−0.332	−0.160	0.004
	L	**0.855**	−0.150	−0.289	−0.166	0.025
Step Length M	R	**0.609**	−0.063	0.167	−0.226	−0.018
	L	**0.875**	−0.258	−0.081	−0.084	0.058
Stride Length M	R	**0.759**	−0.340	−0.132	0.330	0.099
	L	**0.885**	−0.102	0.033	0.251	0.027
Gait Speed CoV	R	−0.226	**0.744**	0.478	0.138	0.177
	L	−0.182	**0.781**	0.461	0.094	0.143
Step Length CoV	R	−0.346	**0.807**	0.200	0.203	0.006
	L	−0.175	**0.902**	−0.057	0.141	0.084
Stride Length CoV	R	−0.204	0.151	−0.109	**0.783**	0.122
	L	0.115	0.212	0.241	**0.727**	−0.038
Step Width M	R	−0.065	0.164	**0.933**	0.016	−0.003
	L	−0.145	0.203	**0.858**	0.047	0.028
Step Width CoV	R	−0.034	0.148	−0.072	0.082	**0.838**
	L	0.139	0.041	0.121	−0.005	**0.849**
Variance Explained (%): 80.0		**26.8**	**19.0**	**15.2**	**9.5**	**9.5**

Note. Factors extracted by principal component analysis and rotated by varimax with Kaiser normalization. Loadings larger than ±0.5 are shown in bold type. M, mean; CoV, coefficient of variation calculated with the formula [SD/Mean] x 100%; R, right limb; L, left limb.

Table 6
Factor loadings of gait dual task costs per limb for the Forced-left condition.

		Factors			
	Limb	**FL-PC1**	**FL-PC2**	**FL-PC3**	**FL-PC4**
Gait Speed M	R	**0.848**	−0.201	−0.176	0.011
	L	**0.872**	−0.101	−0.162	0.016
Step Length M	R	**0.625**	0.210	−0.178	−0.001
	L	**0.927**	−0.053	−0.145	0.027
Stride Length M	R	**0.902**	0.036	0.020	0.139
	L	**0.852**	−0.182	0.270	0.066
Gait Speed CoV	R	−0.163	**0.700**	**0.531**	0.181
	L	−0.139	**0.675**	**0.565**	0.162
Step Length CoV	R	−0.286	0.198	**0.731**	0.005
	L	−0.256	0.267	**0.751**	0.074
Stride Length CoV	R	0.203	0.287	**0.547**	0.154
	L	0.009	−0.183	**0.721**	0.062
Step Width M	R	0.014	**0.844**	−0.046	0.098
	L	−0.062	**0.875**	0.130	−0.009
Step Width CoV	R	0.070	0.016	0.272	**0.845**
	L	0.085	0.179	−0.021	**0.866**
Variance Explained (%): 73.8		**28.2**	**17.6**	**17.5**	**9.9**

Note. Factors extracted by principal factor analysis and rotated by varimax with Kaiser normalization. Loadings larger than ±0.5 are shown in bold type. M, mean; CoV, coefficient of variation calculated with the formula [SD/Mean] x 100%; R, right limb; L, left limb.

4.2. PCA structures of lateralized gait outcomes under baseline and dichotic listening

The second goal of the study was to understand whether our dual-task paradigm had an impact on the lateralized outcomes that would be reflected in the lateralized PCA structures.

4.2.1. Lateralized PCA in baseline

By entering lateralized gait outcomes, (i.e, separate values for each limb) into a PCA for baseline showed a five-factor solution that agrees with previous reports relying on bilateral measures and using the same variables (e.g., Hollman et al., 2011; Verlinden et al., 2013). Correspondingly, each factor was labeled in agreement with the literature. The first factor represented "pace" (Hollman et al., 2011), the second "pace variability" (Verlinden et al., 2013), the third "base of support" (Ofluoglu, Esquenazi, & Hirai, 2003), the fourth "base of support variability" (Ofluoglu et al., 2003) and the fifth "stability" (Maki, 1997).

The fact that the lateralized solution concurs better with earlier reports than the bilateral solution is noteworthy. We regard this discrepancy as the result of limited number of gait parameters entered in the bilateral analysis. By entering separate outcomes by limb in the lateralized analysis causes that specific gait measures become clustered individually, such as in the case of M and CoV of step width, which translates into a better definition of the factor structure. Another important remark is that the lateralized solution shows the existence of subtle natural differences between limbs, which indicates the existence of normal asymmetries in healthy individuals (Sadeghi, Allard, Prince, & Labelle, 2000).

4.2.2. Lateralized PCA during dichotic listening conditions

From the series of PCAs conducted in the dichotic listening conditions three different factor solutions were found. By observing the differences, it was evident that the factor presenting repeatedly higher loadings and explaining the highest percentage of the variance was the “pace” domain, which appeared as the first factor in all three solutions. Because high loadings were present on this factor, we conclude that this is the gait domain most affected by dichotic listening, which agrees with early studies showing a recurrent association between independent gait measures and tests of attention (Morris, Lord, Bunce, Burn, & Rochester, 2016). Thereafter, the “pace variability” domain is equally affected by dichotic listening as it appeared as the second or third factor in the PCA structures of all conditions. However, the number of variables loading on this factor were not completely constant. Only three DTCs-CoVs measures loaded on the NF-PC2 factor for Non-Forced condition with bilateral loadings from gait speed and unilateral loading from left step length. For the Forced-Right condition, DTCs-CoVs values from both limbs loaded highly on this factor. In the Forced-Left condition, the “pace variability” domain appeared as a third factor comprising bilateral DTCs-CoVs from three gait parameters. Consequently, these data point to an effect of dichotic listening on “pace variability” disregarding attentional demands of the different conditions. These results are also in line with reports demonstrating a relationship between executive functions/attention and outcomes of pace variability (Holtzer et al., 2012). There was another constant domain regrouping higher loadings of DTCs-CoVs of step width, which was named “base of support variability”. This factor was the one with the lowest percentage accounting for the total variance in the models. Still, the fact that it always survived the cut-off criteria for selection of factors (i.e., eigenvalues $\geq$1) suggests that dichotic listening alters conspicuously this gait domain. Previous investigations have failed to demonstrate a clear association between independent measures of step width variability and attention in older adults (Morris et al., 2016). Only studies addressing treadmill walking have been able to establish an assotiation between step width outcomes and attentional demands in younger populations (e.g. Grabiner, Marone, Wyatt, Sessoms, & Kaufman, 2018).

As a whole, it was evident that the PCA solution during dichotic listening that was most similar to that of baseline was the factor structure during the Forced-Right condition. This finding suggests that right-handed older adults who attend stimuli from their dominant ear preserve their gait domains practically unchanged, as in regular walking. Though, the high loadings of DTCs found on each domain indicate that focusing attention to the right-side affects all gait domains in right-handed seniors without perturbing their PCA structure. In other words, we believe that the effects of Forced-right condition on the gait structure are not as deleterious as in the other dichotic listening conditions. Since right-handed older persons do not have difficulties with selective right-ear attention (Andersson et al., 2008), it is likely that attending to the dominant ear occurs in an automatic manner, even during walking, which does not cause major intereference with gait. In contrast, the Forced-Left condition, demanding higher control of attention, showed a distinct PCA solution than the one obtained in Forced-Right condition. Of interest is that the main impact of this condition were on the “pace” and “pace variability” domains. Because three out of the four factors comprised variability DTCs and more than half of the high-loading variables were related to DTCs-CoVs, we suggest that voluntary control of attention to the non-dominant ear creates specific difficulties for gait domains comprising variability parameters. Regarding the factor solution in the Non-Forced condition, it was completely different than the other dichotic listening conditions and baseline. Apart from the domain of pace (NF-PC1) and base of support (NF-PC5) no other gait domain was clearly replicated. On the contrary, new factors appeared indicating that this condition greatly disturbed the PCA structure of gait.

All-in-all the present findings document that dichotic listening perturbs mainly the “pace” domain of gait. This finding agrees with the suggestion that pace in older adults is related to executive functions and higher control of attention (Morris et al., 2016). Indeed, we observed that changes in gait caused by dichotic listening were strongly associated with the pace domain not only in the Forced-Left condition where specifically executive mechanisms are required. In fact, “pace” was associated to spontaneous attention and a general voluntary control of attentional focus. Also, these results made clear that dichotic listening does not affect the “pace” domain asymmetrically as we had proposed earlier (Gorecka et al., 2018).

4.3. Does dichotic listening affects the PCA structure of gait asymmetrically?

Now, regarding the second goal of the study about possible lateralized effects of dichotic listening, on gait domains, we confirmed this statement only in the Non-Forced condition. Our tentative hypothesis about obtaining possible lateralized changes on gait structures in the conditions where voluntary control of attention was required, was not supported by the data. When we analyzed raw gait data, we observed asymmetric differences on the Non-Forced and Forced-Left conditions. Notwithstanding, by employing PCA in this study it was evident that only the Non-Forced condition dismantle the domains on which M and CoV of step length and step width recurrently converge. In other words, the “base of support”, “base of support variability” and “stability” domains were affected in a lateralized way during the Non-Forced condition. From the visual inspection of Table 4, we realized that Non-Forced causes a clear separation of the right/left DTCs in stride length CoV and step width M. It turned out that these variables had perfect separated loadings of left and right limbs into different factors. Additionally, the change produced by dichotic listening on DTCs-Ms of gait speed and step length also demonstrated crossed loadings of the right limb, which were spread out into two factors. One of these factors (NF-PC3) actually comprises moderate to high loadings of right limb for the latter variables as well as from the right DTCsM step width.

Taken together, the above results suggest that spontaneous attention assessed by the Non-Forced condition disrupts asymmetrically the “stability” and “base of support” domains of gait. It is important to keep in mind that performance of the Non-Forced condition relies on “bottom-up” answers based on basic perceptual reactions (Hugdahl, 2016). Hence, even though this condition has been suggested to be as of limited difficulty (Hugdahl et al., 2009), it poses enough effort for older adults to asymmetrically disrupt their gait patterns in the mentioned domains. These findings also confirm our previous assertion presented in 2018 that the Non-Forced condition is not an easy situation for older people. As for the other dichotic listening conditions in which volitional control of attention is required, results did not show any lateralized effect on any gait domain.

To sum up, this study has shown the value of using PCA techniques to evaluate the effects of a secondary task on gait domains. The strength of our investigation is the innovative exploration of whether a dual-task paradigm modifies gait domains. By applying a robust lateralized attentional test, such as dichotic listening during walking, we were able to evaluate how varying degrees of attentional control in the same sensorial modality influence overriding aspects of gait. To our knowledge, there is no previous attempt to disclose whether the gait structure of a specific population is modulated by concomitant cognitive actions during dual-tasking. Only one previous study has addressed the effects of dual-tasking on gait domains (Ceïde, Ayers, Lipton, & Verghese, 2018). However, this investigation cannot be directly comparable to our findings as the authors aimed to reduce raw gait data in order to obtain gait domains as predictors of dementia. Besides, most of the attempts to understand the relationship cognition-gait have been conducted through independent associations of gait measurements during single walking and cognitive status (Morris et al., 2016).

Finally, the limitations of this study should be considered. To begin with, we included mainly spatial measures of gait. Although, there is no rule of thumb concerning the number and type of variables employed for obtaining PCA of gait, it would be appropriate that future investigations broaden the evaluation of dichotic listening effects to temporal domains of gait in older adults. Another limitation regards the sample of older adults studied in this investigation. Most of our participants were high functioning individuals, which limits generalization to community-dwelling older person with diverse health conditions affecting their mobility or cognitive abilities. In addition, even if the sample was right-handed there were several participants with mixed foot preference. Potentially, this may have affected the results. To our knowledge, there are no accounts in the scientific literature about the relationship hand-foot preferences in Scandinavian older populations, which leaves the question open as to whether this peculiarity of our sample is of relevance for the findings. Lastly, our study is just observational, and thus it is not possible to quantify or objectively compare the effects of the attentional conditions on the gait structure of older adults. For this reason, it could be argued that our findings are fortuitous. However, the study is highly controlled experimentally and under the same rigorous conditions subjects were required to walk under single-walking and dual-tasking. The fact that we obtained a factor structure during single-walking corroborating past investigations on gait, give us the certainty that at least during baseline conditions our participants display well-known gait domains. Thus, even though the differences observed on the gait structures under the dichotic listening conditions cannot be statistically compared, a reasonable interpretation is that the attentional demands under dichotic listening have an impact on gait domains. We consider that these findings are more than suggestive and they deserve to be further corroborated in other populations.

5. Conclusion

The present study suggests that dichotic listening as a concomitant task to walking, affects the “pace” and “pace variability” domains of gait in a sample of healthy older adults. Results also suggest that all dichotic listening conditions had an effect on “base of support variability”. However, this finding should be taken with caution as this factor accounted for a rather reduced percentage of the variance across all conditions. Notwithstanding, the most interesting finding is that spontaneous attention seems to disrupt gait domains asymmetrically, mainly to the right limb.

The present study addresses a basic research question on the interrelationship of cognition and gait, namely the possibility that different attentional demands on the auditory modality modify gait domains. As mentioned in the introduction, there are several methodological challenges in dual-task research that hinder our understanding on how cognitive constraints alter gait in aging populations (Rochester, Galna, Lord, & Burn, 2014). Some of these concerns relate to variations in type of cognitive task applied, use of complex cognitive tests without ecological validity as well as evaluation of isolated gait parameters. Thus, we estimate that the present study contributes to better appraise the importance of auditory attentional control on overriding gait characteristics of the older adult. With regard to practical applications of the present data, it is mandatory that future research corroborate whether other healthy populations, such as healthy younger people, also display similar alterations on their gait structure as those reported in this study. The potential clinical use of our methodology relies on the possibility to monitor the effectiveness of therapeutic interventions on the gait structure of older patients as well as in the detection of pathology among aging populations.

CRediT author statement

Claudia Rodríguez-Aranda: conceptualization, analyses, writing, supervision, revision and funding. Marta Gorecka: Project administration and data curation. Olena Vasylenko: Project administration. Susana Castro-Chavira: analyses, revision and writing. All authors have reviewed the manuscript and approved of its contents.

Funding

This work was supported by Nasjonalforeningen for folkehelsen (2016/4882 & 2014/888); and UiT The Arctic University of Norway (2016/5455).

Declaration of Competing Interest

The authors have no conflict of interest to disclose.

Acknowledgements

The authors thank Matilde Klaussen for helping with data acquisition.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.humov.2020.102720.

References

Andersson, M., Reinvang, I., Wehling, E., Hugdahl, K., & Lundervold, A. J. (2008). A dichotic listening study of attention control in older adults. *Scandinavian Journal of Psychology, 49*(4), 299–304.

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *Manual for the Beck depression inventory-II.* San Antonio: TX: Psychological Corporation.

Bernal, A. G., Becerro-de-Bengoa-Vallejo, R., & Losa-Iglesias, M. E. (2016). Reliability of OptoGait portable-photoelectric-cell system for the quantification of spatial-temporal parameters of gait in young adults. *Gait & Posture, 50*, 196–200. https://doi.org/10.1016/j.gaitpost.2016.08.035.

Briggs, G. G., & Nebes, R. D. (1975). Patterns of hand preference in a student population. *Cortex, 11*, 230–238.

Buitenweg, J. I. V., Murre, J. M. J., & Ridderinkhof, K. R. (2012). Brain training in progress: A review of trainability in healthy seniors. *Frontiers in Human Neuroscience, 6*, 183. https://doi.org/10.3389/fnhum.2012.00183.

Carbajales-Lopez, J., Becerro-de-Bengoa-Vallejo, R., Losa-Iglesias, M. E., Casado-Hernandez, I., Benito-De Pedro, M., Rodriguez-Sanz, D., et al. (2020). The OptoGait motion analysis system for clinical assessment of 2D Spatio-temporal gait parameters in young adults: A reliability and repeatability observational study. *Applied Sciences-Basel, 10*. https://doi.org/10.3390/app10113726.

Ceïde, M. E., Ayers, E. I., Lipton, R., & Verghese, J. (2018). Walking while talking and risk of incident dementia. *The American Journal of Geriatric Psychiatry, 26*(5), 580–588. https://doi.org/10.1016/j.jagp.2017.12.009.

Corballis, M. C., Badzakova-Trajkov, G., & Haberling, I. S. (2012). Right hand, left brain: Genetic and evolutionary bases of cerebral asymmetries for language and manual action. *Wiley Interdisciplinary Reviews: Cognitive Science, 3*, 1–17. https://doi.org/10.1002/wcs.158.

Decker, L. M., Cignetti, F., Hunt, N., Rodríguez-Aranda, C., Potter, J. F., Stergiou, N., et al. (2017). Effects of aging on the relationship between cognitive demand and step variability during dual-task walking (vol 38, 363, 2016). *Geroscience, 39*, 357–358. https://doi.org/10.1007/s11357-017-9974-x.

Elias, L. J., Bryden, M. P., & Bulman-Fleming, M. B. (1998). Footedness is a better predictor than is handedness of emotional lateralization. *Neuropsychologia, 36*, 37–43.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7*, 336–353. https://doi.org/10.1037/1528-3542.7.2.336.

Federolf, P. A., Boyer, K. A., & Andriacchi, T. P. (2013). Application of principal component analysis in clinical gait research: Identification of systematic differences between healthy and medial knee-osteoarthritic gait. *Journal of Biomechanics, 46*(13), 2173–2178. https://doi.org/10.1016/J.JBIOMECH.2013.06.032.

Folstein, M. F., Folstein, S. F., & McHugh, P. R. (1975). Mini mental state: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189–198.

Gorecka, M. M., Vasylenko, O., Espenes, J., Waterloo, K., & Rodríguez-Aranda, C. (2018). The impact of age-related hearing loss and lateralized auditory attention on spatiotemporal parameters of gait during dual-tasking among community dwelling older adults. *Experimental Gerontology, 111*(February), 253–262. https://doi.org/10.1016/j.exger.2018.07.015.

Gorecka, M. M., Vasylenko, O., & Rodríguez-Aranda, C. (2020). Dichotic listening while walking: A dual-task paradigm examining gait asymmetries in healthy older and younger adults. *Journal of Clinical and Experimental Neuropsychology, 42*, 794–810. https://doi.org/10.1080/13803395.2020.1811207.

Grabiner, M. D., Marone, J. R., Wyatt, M., Sessoms, P., & Kaufman, K. R. (2018). Performance of an attention-demanding task during treadmill walking shifts the noise qualities of step-to-step variation in step width. *Gait & Posture, 63*, 154–158. https://doi.org/10.1186/1743-0003-2-25.

Guffey, K., Regier, M., Mancinelli, C., & Pergami, P. (2016). Gait parameters associated with balance in healthy 2-to 4-year-old children. *Gait & Posture, 43*, 165–169. https://doi.org/10.1016/j.gaitpost.2015.09.017.

Hausdorff, J. M., Rios, D. A., & Edelberg, H. K. (2001). Gait variability and fall risk in community-living older adults: A 1-year prospective study. *Archives of Physical Medicine and Rehabilitation, 82*, 1050–1056. https://doi.org/10.1053/apmr.2001.24893.

Hirnstein, M., Hugdahl, K., & Hausmann, M. (2014). How brain asymmetry relates to performance – A large-scale dichotic listening study. *Frontiers in Psychology, 4* (JAN), 997. https://doi.org/10.3389/fpsyg.2013.00997.

Hollman, J. H., Mcdade, E. M., & Petersen, R. C. (2011). Normative spatiotemporal gait parameters in older adults. *Gait & Posture, 34*, 111–118. https://doi.org/10.1016/j.gaitpost.2011.03.024.

Holtzer, R., Wang, C., & Verghese, J. (2012). The relationship between attention and gait in aging: Facts and fallacies. *Motor Control, 16*(1), 64–80.

Hommet, C., Mondon, K., Berrut, G., Gouyer, Y., Isingrini, M., Constans, T., & Belzung, C. (2010). Central auditory processing in aging: The dichotic listening paradigm. *The Journal of Nutrition, Health & Aging, 14*(9), 751–756. https://doi.org/10.1007/s12603-010-0097-7.

Hugdahl, K. (1995). Dichotic listening: Probing temporal lobe functional integrity. In R. J. Davidson, & K. Hugdahl (Eds.), *Brain asymmetry* (pp. 123–156). Cambridge, Massachussets: MIT Press.

Hugdahl, K. (2003). Dichotic listening in the study of auditory laterality. In K. Hugdahl, & R. J. Davidson (Eds.), *The Asymmetrical Brain* (pp. 441–475). London: The MIT Press https://doi.org/10.7551/mitpress/1463.003.0017.

Hugdahl, K. (2011). Hemispheric asymmetry : Contributions from brain imaging. *WIREs Cognitive Science, 2*, 461–478. https://doi.org/10.1002/wcs.122.

Hugdahl, K. (2016). Dichotic listening and attention: The legacy of Phil Bryden. *Laterality, 21*(4–6), 433–454. https://doi.org/10.1080/1357650X.2015.1066382.

Hugdahl, K., Westerhausen, R., Alho, K., Medvedev, S., Laine, M., & Hämäläinen, H. (2009). Attention and cognitive control: Unfolding the dichotic listening story. *Scandinavian Journal of Psychology, 50*(1), 11–22. https://doi.org/10.1111/j.1467-9450.2008.00676.x.

Jayakody, D. M. P., Friedland, P. L., Martins, R. N., & Sohrabi, H. P. (2018). Impact of Aging on the Auditory System and Related Cognitive Functions: A Narrative Review. *Frontiers in Neuroscience, 12*. https://doi.org/10.3389/fnins.2018.00125.

Jolliffe, I. T., & Cadima, J. (2016). Principal component analysis: A review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374*(2065). https://doi.org/10.1098/rsta.2015.0202, 20150202.

Lezak, M. D. (1995). *Neuropsychological assessment* (3rd ed.). New York: Oxford University Press.

Lienhard, K., Schneider, D., & Maffiuletti, N. A. (2013). Validity of the Optogait photoelectric system for the assessment of spatiotemporal gait parameters. *Medical Engineering & Physics, 35*, 500–504. https://doi.org/10.1016/j.medengphy.2012.06.015.

Loge, J. H., Kaasa, S., Hjermstad, M. J., & Kvien, T. K. (1998). Translation and performance of the Norwegian SF-36 health survey in patients with rheumatoid arthritis. I. Data quality, scaling assumptions, reliability, and construct validity. *Journal of Clinical Epidemiology, 51*, 1069–1076.

Lord, S., Galna, B., Verghese, J., Coleman, S., Burn, D., & Rochester, L. (2013). Independent domains of gait in older adults and associated motor and nonmotor attributes : Validation of a factor analysis approach. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 68*(7), 820–827. https://doi.org/10.1093/gerona/gls255.

Loughrey, D. G., Kelly, M. E., Kelley, G. A., Brennan, S., & Lawlor, B. A. (2018). Association of age-related hearing loss with cognitive function, cognitive impairment, and dementia a systematic review and meta-analysis. *Jama Otolaryngology-Head & Neck Surgery, 144*, 115–126. https://doi.org/10.1001/jamaoto.2017.2513.

Maki, B. E. (1997). Gait changes in older adults: Predictors of falls or indicators of fear? *Journal of the American Geriatrics Society, 45*(3), 313–320. https://doi.org/10.1111/j.1532-5415.1997.tb00946.x.

Montero-Odasso, M., Verghese, J., Beauchet, O., & Hausdorff, J. M. (2012). Gait and cognition: A complementary approach to understanding brain function and the risk of falling. *Journal of the American Geriatrics Society, 60*, 2127–2136. https://doi.org/10.1111/j.1532-5415.2012.04209.x.

Morris, R., Lord, S., Bunce, J., Burn, D., & Rochester, L. (2016). Gait and cognition: Mapping the global and discrete relationships in ageing and neurodegenerative disease. *Neuroscience and Biobehavioral Reviews, 64*, 326–345. https://doi.org/10.1016/j.neubiorev.2016.02.012.

Muir-Hunter, S. W., & Wittwer, J. E. (2016). Dual-task testing to predict falls in community-dwelling older adults: A systematic review. *Physiotherapy, 102*(1), 29–40. https://doi.org/10.1016/j.physio.2015.04.011.

Nordin, E., Moe-Nilssen, R., Ramnemark, A., & Lundin-Olsson, L. (2010). Changes in step-width during dual-task walking predicts falls. *Gait & Posture, 32*, 92–97. https://doi.org/10.1016/j.gaitpost.2010.03.012.

Ofluoglu, D., Esquenazi, A., & Hirai, B. (2003). Temporospatial parameters of gait after obturator Neurolysis in patients with spasticity. *American Journal of Physical Medicine & Rehabilitation, 82*(11), 832–836. https://doi.org/10.1097/01.PHM.0000091986.32078.CD.

Paquet, N., Taillon-Hobson, A., & Lajoie, Y. (2014). Fukuda and Babinski-Weil tests: Within-subject variability and test-retest reliability in nondisabled adults. *Journal of Rehabilitation Research and Development, 51*, 1013–1022.

Pashler, H. (1994). Dual-task interference in simple tasks - data and theory. *Psychological Bulletin, 116*, 220–244.

Passow, S., Westerhausen, R., Hugdahl, K., Wartenburger, I., & Heekeren, H. R. (2014). Electrophysiological correlates of adult age differences in attentional control of auditory processing. *Cerebral Cortex, 24*, 249–260. https://doi.org/10.1093/cercor/bhs306.

Rochester, L., Galna, B., Lord, S., & Burn, D. (2014). The nature of dual-task interference during gait in incident Parkinson'S disease. *Neuroscience, 265*, 83–94. https://doi.org/10.1016/j.neuroscience.2014.01.041.

Sadeghi, H., Allard, P., Prince, F., & Labelle, H. (2000). Symmetry and limb dominance in able-bodied gait: A review. *Gait & Posture, 12*, 34–45.

Shaukat, S. S., Rao, T. A., & Khan, M. A. (2016). Impact of sample size on principal component analysis ordination of an environmental data set: Effects on eigenstructure. *Ekólogia (Bratislava), 35*, 173–190. https://doi.org/10.1515/eko-2016-0014.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics* (5th ed.). Boston: Allyn & Bacon/Pearson Education.

Van Eyken, E., Van Camp, G., & Van Laer, L. (2007). The complexity of age-related hearing impairment: Contributing environmental and genetic factors. *Audiology and Neuro-Otology, 12*, 345–358. https://doi.org/10.1159/000106478.

Verghese, J., Holtzer, R., Lipton, R. B., & Wang, C. (2009). Quantitative gait markers and incident fall risk in older adults. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 64*(8), 896–901. https://doi.org/10.1093/gerona/glp033.

Verghese, J., Wang, C., Lipton, R. B., Holtzer, R., & Xue, X. (2007). Quantitative gait dysfunction and risk of cognitive decline and dementia. *Journal of Neurology, Neurosurgery, and Psychiatry, 78*(9), 929–935. https://doi.org/10.1136/jnnp.2006.106914.

Verlinden, V. J. A., Van der Geest, J. N., Hoogendam, Y. Y., Hofman, A., Breteler, M. M. B., & Ikram, M. A. (2013). Gait patterns in a community-dwelling population aged 50 years and older. *Gait and Posture, 37*, 500–505. https://doi.org/10.1016/j.gaitpost.2012.09.005.

Viljanen, A., Kaprio, J., Pyykko, I., Sorri, M., Pajala, S., Kauppinen, M., et al. (2009). Hearing as a predictor of falls and postural balance in older female twins. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 64*, 312–317. https://doi.org/10.1093/gerona/gln015.

Wayne, R. V., & Johnsrude, I. S. (2015). A review of causal mechanisms underlying the link between age-related hearing loss and cognitive decline. *Ageing Research Reviews, 23*, 154–166. https://doi.org/10.1016/j.arr.2015.06.002.

Westerhausen, R., & Hugdahl, K. (2008). The corpus callosum in dichotic listening studies of hemispheric asymmetry: A review of clinical and experimental evidence. *Neuroscience and Biobehavioral Reviews, 32*, 1044–1054. https://doi.org/10.1016/j.neubiorev.2008.04.005.

Wickens, C. D. (2008). Multiple resources and mental workload. *Human Factors, 50*, 449–455. https://doi.org/10.1518/001872008X288394.

Wollesen, B., Wanstrath, M., van Schooten, K. S., & Delbaere, K. (2019). A taxonomy of cognitive tasks to evaluate cognitive-motor interference on spatiotemoporal gait parameters in older people: A systematic review and meta-analysis. *European Review of Aging and Physical Activity, 16*. https://doi.org/10.1186/s11556-019-0218-1.