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The Impact of Age-related Hearing Loss and Lateralized Auditory Attention on Spatiotemporal Parameters of Gait During Dual-tasking Among Community Dwelling Older Adults

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Abstract

This investigation assessed the impact of hearing loss and lateralized auditory attention on spatiotemporal parameters of gait during overground dual-tasking by the use of the dichotic listening task. Seventy-eight right-handed, healthy older adults between 60 and 88 years were assigned to a Young-Old (<70 years) or an Old-Old (>71 years) group. Cognitive assessment and pure tone audiometry were conducted. Spatiotemporal parameters of gait quantified by mean (*M*), and coefficient of variations (CoV) were evaluated with the OptoGait system during 3 dichotic listening conditions: Non-Forced, Forced-Right and Forced-Left. Factorial analyses of variance and covariance were used to assess group differences and the moderating effects of hearing status, respectively. Results demonstrated that three of the gait parameters assessed were affected asymmetrically by the dual-task paradigm after controlling for hearing status. Asymmetries existed on step width, gait speed and variability of stride length. Finally, correlations between gait outcomes and dichotic listening results showed that *M* and CoVs in gait parameters during right-ear responses were longer compared with left-ear. Left-ear responses were related to increased variability on stride length, which indicates higher difficulty level. Hearing status varying from normal to mild levels of hearing loss modulates spatiotemporal gait outcomes measured during dichotic listening execution. Findings suggest that attending to left side stimuli relates to increased gait variability, while focusing on right-side assures a safe walk. Results demonstrated that attending to right-ear stimuli is an adaptive strategy for older adults that compensates for limited sensorimotor and cognitive resources during walking.

Key words: Hearing loss, dichotic listening, healthy aging, cognitive decline, walking overground

The impact of age-related hearing loss and lateralized auditory attention on spatiotemporal parameters of gait during dual-tasking among community dwelling older adults

The “dual-task paradigm” has been broadly employed to study aging effects on multitasking, and more specifically, on the interplay of gait and cognition. This paradigm is used to disentangle the possible causes of falls in older populations. Notwithstanding, there are some caveats. One is the absence of appropriate rationale for the selection of the cognitive tasks challenging gait. Since type of cognitive task used during walking matters (Beauchet, Aminian, Gonthier, & Kressig, 2005), tests measuring specific cognitive mechanisms that can be naturally adapted on dual-tasking should be prioritized. A second limitation is the lack of information about the role of sensory loss influencing the gait-cognition association. To our knowledge, the very common condition of age-related hearing loss among older adults over 60 years has not yet been explored in dual-task investigations.

Age-related hearing loss (ARHL) or presbycusis is a chronic, degenerative condition following accumulating extrinsic and intrinsic factors resulting in impairments in cochlear transduction of acoustic signals (Huang & Tang, 2010). ARHL is also one of the most prevalent chronic conditions in the older population (Yamasoba et al., 2013). As it is well established, ARHL aggravates with increasing age and it goes hand by hand with declined cognition (Lin et al., 2011). It is calculated that 37% of older persons between 60-70 years have a hearing loss over 25dB, while the proportion elevates to 60% among those over 70 years (Van Eyken, Van Camp, & Van Laer, 2007). Whether ARHL and cognitive decline arise due to a common etiology or as a result of a direct link between the two phenomena (Wayne & Johnsrude, 2015) is still a matter of debate. Nonetheless, hearing loss and cognitive deficits co-exist in the older adult and both conditions have been associated with impaired functional status (Chen et al., 2015) and increased risk of falls (Lopez et al., 2011). To our knowledge, there are only two earlier studies addressing the issue of hearing loss and dual-tasking (Lau, Pichora-Fuller, Li, Singh, & Campos, 2016; Bruce et al., 2017).

Because hearing loss is closely connected to cognitive decline in aging and it also affects walking and balance (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011) it is important to take the condition into account in dual-task studies. A central interest is to understand the relevance of sensorimotor changes due to aging when walking, listening and talking occur concurrently. In fact, such a scenario has been addressed under experimental conditions using the dichotic listening test (DL) (Decker, Cignetti, & Stergiou, 2013; Decker et al., 2017). DL is a robust task for the study of divided attention and executive function in which participants need to attend to specific auditory information during trials where competing stimuli are simultaneously applied to both ears. During three conditions subjects are required to report information based on a self-selected choice or from one specific ear. DL tests hemispheric lateralization of language and the fact that the brain mechanisms underlying DL performance are well-known is of great interest for dual-task research. The benefit of the test is its ability to assess attention across different levels of task difficulty as well as possible asymmetrical effects on gait due to lateralized focus of attention.

Why does lateralized focus of auditory attention influence gait asymmetrically?

In order to answer this question, we need to address the topic of hemispheric specialization in aging and specifically in DL and gait. With increasing age, hemispheric specialization tends to diminish as observed in functional imaging studies (Cabeza, 2002). However, hemispheric specialization is differently affected by age depending on the cognitive modality or function under consideration. For instance, during performance of the DL test, right-handed older adults demonstrate larger difficulties to report stimuli from left-ear while their ability to report from right ear is more accentuated (Stecker, McLaughlin, & Higgins, 2015). The preference for right-ear stimuli is a phenomenon called “the right ear advantage”, which exists in all right-handed subjects and is explained by the left-hemispheric dominance for language processing (Hugdahl, 1988). In contrast, processing of left-ear stimuli is more challenging as information coming from left-ear is transmitted via the anatomical decussation of fiber pathways to the right hemisphere. There, the signal has to be further transferred through corpus callosum to the left hemisphere for final processing (Hugdahl, Westerhausen, Alho, Medvedev, & Hamalainen, 2008). Thus, the difficulty to report stimuli from left-ear in aging is thought to be caused by decreased inter-hemispheric transfer of the auditory input, probably due to size reduction of the corpus callosum (Westerhausen, Bless, & Kompus, 2015).

Concerning the effects of aging on lateralized organization of motor functions, findings depend on the action in question. For example, in upper-limb function preservation of lateralized capacities has been documented (Sebastjan, Skrzek, Ignasiak, & Slawinska, 2017). As for walking, the situation is quite different. In healthy individuals gait is a rather symmetric function (Viteckova et al., 2018), controlled by basic spinal motor programs that keep movement synchronization (Ivanenko, Poppele, & Lacquaniti, 2006). However, under specific contexts like in dual-tasking, the nervous system needs to integrate additional sensorimotor information by utilizing higher-level cortical functions and volitional actions. These events perturb central generator patterns for locomotion (Ivanenko et al., 2006; Robinson & Kiely, 2017). In aging, walking becomes a more demanding action and more involvement of executive functions and attention is required (Yogev-Seligmann, Hausdorff, & Giladi, 2008). Thus, additional cognitive loading in dual-tasking further disturbs gait patterns.

In the past, few studies have evaluated the effects of the concomitant cognitive task on gait asymmetries in healthy older adults, probably because asymmetries are regarded as a pathological feature (Yogev, Plotnik, Peretz, Giladi, & Hausdorff, 2007). One of these studies evaluated gait asymmetries by the use of a verbal fluency test (Dalton, Sciadas, & Nantel, 2016), but data only showed a trend towards disrupted asymmetry. In another recent investigation, arm swing asymmetries in healthy older adults have been reported during execution of a dual-task employing the Stroop test (Killeen et al., 2017). Authors of this study remark the absence of information about asymmetric effects for lower limbs, implying that gait asymmetries might not arouse by dual-tasking in healthy populations. However, this is still an open question as for now, most of the cognitive tests adopted in dual-task research do not deliberately assess lateralized cognitive functions. Therefore, in the present study we used the DL test, which increases cognitive load in a lateralized way. Since DL performance recruits higher attentional resources on one brain hemisphere (Tervaniemi & Hugdahl, 2003), a lateralized cortical activation during DL is superimposed to motor programmes acting on both sides of the corticospinal pathway that control both sides of the body. Hence, it is reasonable to expect that lateralized focus of attention will disrupt coordination of these motor programmes asymmetrically.

Interest of the present study

The use of DL as a secondary task has only been investigated during walking on a treadmill (Decker et al., 2013; Decker et al., 2017). Because it is well documented that walking on a treadmill modifies the way in which participants ambulate (Hollman et al., 2016), findings from these studies cannot generalize to normal walking, it is necessary to assess DL in dual-tasking during overground walking. In addition, gait studies using treadmills augment the attentional requirements as achievement of a steady walk on the device increases the cognitive load and subjects tend to prioritize walking at the expense of the secondary task (Regnaux, Robertson, Ben Smail, Daniel, & Bussel, 2006). This means that the effects exerted by DL need to be investigated on regular walking, especially concerning older adults for whom just walking already demands increased cognitive control (Yogev-Seligmann et al., 2008). For these reasons, it is important to evaluate DL as a secondary task during walking overground, which will bring an optimal ecological valid environment that resembles daily situations. Therefore, the aim of the present study was two-fold: First, evaluate possible asymmetric effects of DL in a dual-task paradigm during walking overground in right-handed healthy older adults and secondly, to assess the moderating effects of hearing loss on this experimental situation.

Method

Participants

Seventy-eight right-handed volunteers ranging in age between 60 and 88 years (*M* = 71.1, SD = 6.6) participated in the dual-task study. All the participants were involved in a larger umbrella project of motor functions and cognition at our institution. Only right-handed individuals were enrolled as it is demonstrated that left-handed people present atypical lateralization patterns (Westerhausen et al., 2015). Because specific age ranges of older adults may have an impact on study results (e.g., (Ihle, Jopp, Oris, Fagot, & Kliegel, 2016), participants were assigned to a Young-Old group (YO, ≤ 70, n =38) or to an Old-Old group (OO, ≥71, n = 40). This approach has been adopted by numerous investigations, and it assures inclusion of specific age-ranges of older adults with different levels of hearing loss and cognitive deficits. Educational level of the whole group was 13 years on average (SD = 3.9), 72% of the participants were retired and 56% were females. All individuals were community living older adults from north-Norway, free of major diseases or cognitive troubles. Inclusion criteria were being right-handed, native Norwegian speaker, above the age of 60, no diagnosis of orthopaedic, motor or other co-morbidities likely to impact gait and cut-off criteria on MMSE >27 to assure normal cognitive status (Petersen et al., 1999). Exclusion criteria were having a diagnosis of pathology that directly affects the musculoskeletal system, recent surgery, acute illness, or cardiac/movement disorders. Participants were also screened for depression with the Beck Depression Inventory II (Beck, Steer, & Brown, 1996) and none of the participants scored within the depression range. Exclusion criteria to avoid high-moderate to severe impaired hearing which may hampering DL execution included averaged pure-tone threshold higher than 45 dB on any ear and interaural asymmetry between ears of not more than 15 dB, which is the clinical definition for asymmetric sensorineural hearing loss (Saliba, Martineau, & Chagnon, 2009). The latter criterion is crucial in the present study due to the interest in evaluating lateralized auditory stimuli in healthy participants. It should be reminded that ARHL is a gradual process affecting both ears in parallel and that any asymmetric impairment suggest the existence of damage to the auditory system beyond normal effects of aging (Howarth & Shone, 2006).

Recruitment of participants was conducted through advertisements at the local senior citizens' center, flyers, and by means of word of mouth. Informed consent was obtained from all participants and they were aware that they could leave the study at any time if they so choose. The study was approved by the Regional Research Ethics Committee.

Measures

Audiometric screening and group assignment. A pure tone audiometry was conducted in all participants for frequencies: 0.25, 0.5, 1, 2, 4 and 8 kHz with a screening audiometer MADSEN Itera II. The average hearing sensitivity reflected by "pure tone averages" (PTA) of the frequencies 0.5, 1, 2 and 4 kHz was calculated for each ear. A score equal to or greater than 25 decibel (dB) on PTAs was used to classify those with impaired hearing, while a score equal to or less than 24 dB on PTAs was the cut-off to classify those with normal hearing (WorldHealthOrganization, 2017). We based group division on worst-PTA, which is the highest threshold presented from the two ears. We employed worst-PTA since this calculation identifies individuals with heavily hearing dysfunction that may affect gait and auditory performance.

Gait assessment and apparatus. Spatio-temporal parameters of gait were acquired during walking in single (only walking) and dual-task situations with the OptoGait photoelectric cell device (Microgate, Bolzano, Italy), which has proved to be a highly reliable and valid instrument (Bernal, Becerro-de-Bengoa-Vallejo, & Losa-Iglesias, 2016). Description of this system has been reported elsewhere (Lienhard, Schneider, & Maffiuletti, 2013). Means and coefficient of variations for gait speed, step length, step width and stride length were calculated and used in statistical analyses. We selected these parameters as they represent the "pace" aspect of the gait cycle (Verghese, Wang, Lipton, Holtzer, & Xue, 2007; Hollman, Mcdade, & Petersen, 2011), which is controlled by subcortical and cortical areas while other gait features such as rhythm (i.e., cadence and various timing measures) are regulated by spinal and brainstem mechanisms (Verghese et al., 2007). For this reason, "pace" parameters have proved to be more sensitive to reduced executive functioning. Gait data were evaluated statistically for both limbs (i.e., average scores calculated by taking together the right and left side data) and for each separate limb to explore lateralized effects of the dual-task. The OptoGait device was placed in a quiet room creating an area of 7 m. long X 1.3 m width in which subjects were asked to walk in rounds at a self-selected comfortable speed. Participants were instructed to use flat shoes with heel not exceeding 3 cm (Kressig & Beauchet, 2006).

Dichotic listening (DL) task. The Bergen dichotic listening paradigm adapted to be presented via the E-Prime software was used. Detailed explanation of the test has been previously reported (Andersson, Reinvang, Wehling, Hugdahl, & Lundervold, 2008). Shortly, two of six possible syllables (BA, DA, GA, KA, PA, TA) are presented dichotically through noise-cancelling headphones in three different conditions of 3 min. each. There are 30 possible combinations of all syllables and 6 trials presenting the same syllables (homonyms). All stimuli were presented in a randomized order at a duration of 450-500 ms. with a 500 ms.

intertrial interval and with three randomizations for each attentional instruction. The first condition (Non-forced), requires participants to report the clearest perceived sound, which indicates side preference of attention (right vs. left ear advantage). Because this is a free choice situation, the NF condition is always presented first. Thereafter, the second and third conditions are presented counterbalanced, depending on the participant's identification number. Subjects assigned with even identification numbers underwent the Forced-Right condition first and subjects with uneven identification numbers received the Forced-Left first. One of these conditions requires participants to report stimuli presented only to the right-ear (Forced-Right condition), while the other requires to report stimuli from left-ear (Forced-Left condition). Competing stimuli from the opposite ear has to be ignored. Scored outcomes reflect correct matched answers for each ear, homonyms, errors and non-responses by condition. Following standard procedures, correct answers are only considered when subjects correctly report an applied stimulus to any of the ears, disregarding the condition evaluated. This means that on every condition there are correct answers for right-ear and left-ear. Homonyms are accounted for when subjects report correctly the same paired stimuli on both ears (ex: BA "right-ear"- BA "left-ear"). Errors are intrusions (i.e., unrelated answers to applied stimuli, ex: answer "PA" when applied stimuli were "BA-DA") and missed homonyms.

Neuropsychological assessment and questionnaires. A test battery including the Trail Making Test A and B (Reitan & Wolfson, 1993), Stroop test (Golden, 1978), Phonemic (Benton, 1967) and Semantic fluency (Newcombe, 1969), Digits span forward and backwards (Wechsler, 2014), Logical Memory I and II Wechsler (Wechsler, 1997), Vocabulary (Wechsler, 2014), Block design (Wechsler, 2014), Purdue Pegboard (Lafayette Instrument Model 32020) and Finger tapping (Reitan & Wolfson, 1993) was applied to obtain a cognitive profile of the participants. In addition, the Waterloo Foot Preference Questionnaire (Elias, Bryden, & Bulman-Fleming, 1998), and the Handedness Questionnaire (Briggs & Nebes, 1975) were used to confirm the laterality preferences of the participants, although all of the volunteers were self-declared as being right-handed. The Falls Efficacy Scale International (FES-I) was employed to evaluate fear of falling while the Norwegian version of the F-36 questionnaire (Loge, Kaasa, Hjermstad, & Kvien, 1998) was used to assess health status.

Procedure

Thorough information on the study was given and informed consent was taken at the beginning of the test sessions. An initial interview was carried out, followed by the neuropsychological test battery, questionnaires and audiometry. Then, after a rest period, the participants executed the dual-task paradigm. First, they were required to only walk during one minute in the OptoGait system to collect baseline measurements for gait. The time assigned to simple walking was based on pilot trials. After single walking, participants performed the dual-task procedure. For dual-tasking, participants were provided with a pair of wireless, noise cancelling head phones. Participants were given sufficient time to understand instructions and adjust the volume until reporting clear perception of the DL stimuli. At this stage, participants selected volume level after being presented with one example of stimulus at 80 dB. Thereafter, participants adjusted the volume over this range and up to 90 dB, which was the highest possible level of audibility for the experiment. Then, participants performed the dichotic listening at the same time that they walked in the OptoGait area. DL test started always with the Non-Forced condition (NF), followed by either the Forced-Right (FR) or Forced-Left (FL) condition, which were presented counterbalanced. Responses were recorded using a digital recorder that was placed around the participant’s neck. A rest was given to the participants between DL conditions. Recording of the oral responses was registered afterwards manually. All responses were recorded and written down by one experimenter at time of testing. After the experiment was completed, both recorded and written responses were checked by a second experimenter who manually recorded all answers into the E-prime software to ensure reliable data. Finally, it is necessary to highlight that we intentionally did not assess DL as single task as we wanted to evaluate the impact of the experimental situation without previous knowledge.

Statistical Analyses

Evaluation of demographics and neuropsychological tests: Group comparisons for demographics, background variables, cognitive tests and questionnaires were performed with independent t-tests.

Evaluation of DL: A series of factorial analyses of variance with repeated measures in one factor with the design 2 Group (Young-Old, Old-Old) X 2 Ear (right, left) X 3 Condition (NF, FR, FL) was used. In case of a significant omnibus test, univariate tests were performed. In case of significant interactions, multivariate tests for simple main effects were carried out.

Evaluation of gait: The mean and coefficient of variations (CoV) were analyzed separately on each gait parameter. Bilateral gait outcomes (i.e., values for both limbs taken together) were first analyzed and then lateralized outcomes (i.e., separate results for right and left limbs). For bilateral analyses a set of mixed-ANOVAs were conducted with the design 4 Condition (Baseline, NF, FR, FL) as the within-subjects factor X 2 Group (Young-Old, Old-Old) as the between-subjects factor. For lateralized analyses of gait, we used two-way ANOVAs with the design: 4 Condition (Baseline, NF, FR, FL) X 2 Foot (right, left) X 2 Group (Young-Old, Old-Old). In all analyses, Geisser-Greenhouse corrections were chosen when the sphericity assumption was not met. Significant interactions or main effects involving group differences were followed up with appropriate post-hoc analyses.

Evaluation of the effects of hearing loss: The impact of hearing loss was tested in a series of ANCOVAs for DL and gait measures by using the PTA-worst values as the covariate. As suggested by Schneider et al. (Schneider, Avivi-Reich, & Mozuraitis, 2015) all values were centered before used as covariates. Also, data were scrutinized to assure compliance of all ANCOVA assumptions, which were met.

Evaluation of the relationship between DL and gait: Pearson's correlations analyses were performed to assess the relationship between DL performance and lateralized results of gait. All analyses were performed with the statistical package IBM SPSS Statistics 23.

Results

Results for demographic variables, handedness, footedness, FES-I and SF-36 are presented in Table 1. Significant group differences in addition to age (*t* (76) = -12.26, p < 0.001) were found for education (*t* (76) = 1.98, p < 0.05) and both PTA values (best: *t* (76) = -4.40, p < 0.001; worst: *t* (76) = -4.90, p < 0.001). As expected the OO group had significantly higher PTA values than the YO participants. Also the OO group had significantly lower education. Results from the Handedness Inventory corroborated that all participants were right handed, as positives scores deviating from zero (i.e., no hand preference) indicate right-hand preference.

Table 1. Participant's demographics and characteristics by age groups

	Young-old (n = 38)		Old-old (n = 40)	
Sex (male/female)	*11/26*		*18/24*	
	M	*(SD)*	*M*	*(SD)*
Age (years)	65.4	(2.9)	76.4	(4.8)***
Education (years)	14.0	(3.5)	12.3	(4.3)*
Height (cm)	168.8	(8.1)	170.2	(8.3)
Handedness	20.7	(3.9)	19.8	(5.2)
Footedness	12.1	(7.7)	10.8	(5.8)
FES-I	19.0	(4.1)	19.9	(3.2)
SF-36	105.2	(6.9)	105.1	(7.8)
PTA best (dB)	17.12	(7.5)	26.6	(11.1)***
PTA worst (dB)	20.38	(8.7)	31.9	(11.9)***

Note: Significant group differences are denoted by: * = $p < 0.05$; ***= $p < 0.001$
Abbreviations: FES-I = Falls Efficacy Scale International, SF-36 = 36-item Short-Form Health Survey, PTA = pure tone average.

Audiometric characteristics: As observed in Table 2, the large majority of subjects in the YO group (68.4%) had normal hearing while only 25% of the OO group had it. As for interaural differences, most of the YO participants, namely 86.8% of this sample, had small threshold differences between ears of not more than 5 dB. Less than 8% differed by 6-10 dB and only 5% had a difference between 11-15 dB. In the OO group 62.5% had a difference equal or lower than 5 dB; 25% presented interaural difference between 6-10 dB and 12% had a difference over 11 dB.

Table 2. Summary of auditory characteristics by group

	Young-old (n = 38)	Old-old (n = 40)
	Number (%)	Number (%)
Hearing status		
Normal (< 25dB)	26 (68.4)	10 (25)
Hearing loss (> 25 dB)	12 (31.6)	30 (75)
Interaural differences		
0-5dB	33 (86.8)	25 (62.5)
6-10 dB	3 (7.9)	10 (25)
11-15 dB	2 (5.3)	5 (12.5)
Best ear by interaural thresholds		
0-5dB		
Right ear	12 (31.6)	16 (40)
Left ear	14 (36.8)	6 (15)
Equal	7 (18.4)	3 (7.5)
6-10 dB		
Right ear	N/A	5 (12.5)
Left ear	3 (7.9)	5 (12.5)
Equal	N/A	N/A
11-15 dB		
Right ear	1 (2.6)	4 (10)
Left ear	1 (2.6)	1 (2.5)
Equal	N/A	N/A

Equal = same threshold on both ears. N/A = not available

Regarding characteristics of the most sensitive ear on each group, we observed that in the YO group 34.2 % of the participants (n = 13) had better sensitivity with right ear, 47.4% with left (n= 18) and 18.4 % (n = 7) had equal sensitivity thresholds on both ears. For the OO group, the large majority of participants (62.5 %, n = 25) had better sensitivity on right ear while only 30% (n =12) had better thresholds with left ear and 7.5% (n =3) presented equal sensitivity in both ears.

Neuropsychological results. These data are shown in Table 3. There were found significant group differences in executive functions (TMT A, $p < 0.05$; TMT B, $p < 0.001$; Stroop test, $p < 0.001$) and attention (Digits span forwards, $p < 0.01$). Further significant differences were found for psychomotor function (all Pegboard measurements, $p < 0.001$), grip strength (right and left, p < 0.01), phonemic repetitions ($p < 0.05$) and semantic fluency answers ($p < 0.01$).

Table 3. Mean (*M*) and Standard deviations (*SD*) by age group for MMSE and neuropsychological tests.

	Young-Old (n = 38)		Old-Old (n = 40)		*t*-score (76)
	M	*SD*	*M*	*SD*	
MMSE	29.08	1.32	28.33	2.20	0.87
TMT (seconds)					
A	34.85	16.81	42.20	14.16	-2.09*
B	75.36	21.38	107.9	33.70	-5.01**
Stroop Test					
Word	91.92	14.39	78.53	15.49	3.95***
Color	64.97	11.28	55.25	8.69	4.27***
Color/Word	34.45	7.89	27.10	7.04	4.34***
Digit span					
Forwards	9.11	1.72	8.08	1.77	2.60**
Backwards	8.11	1.85	7.50	1.75	1.48
Log Memory I	10.39	3.10	10.58	3.80	-0.22
Log Memory II	14.42	3.74	13.53	4.28	0.98
Vocabulary	33.05	5.72	30.70	8.43	1.44
Pegboard					
Right hand	13.08	2.17	10.58	2.14	5.11***
Left hand	11.95	2.08	10.23	2.08	3.62***
Both hands	10.16	1.72	8.33	1.60	4.83***
Assembly	5.92	1.14	4.70	1.18	4.60***
Block Design	36.00	10.89	32.72	9.91	1.38
Finger tapping					
Right	40.38	10.82	39.80	11.32	0.23
Left	38.60	9.71	36.04	9.95	1.14
Grip strength					
Right hand (kg)	31.75	8.31	38.78	11.83	-3.04**
Left hand (kg)	30.54	7.53	37.39	11.47	-3.13**
Phonemic Fluency					
Correct answers	13.67	3.85	12.02	3.52	1.96
Repetitions	0.37	0.40	0.63	0.60	-2.19*
Semantic Fluency					
Correct answers	17.49	3.99	15.06	2.52	3.17**
Repetitions	0.35	0.37	0.46	0.71	-0.78

Note: MMSE = Mini Mental State Examination; TMT = Trail making test.

* = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Dichotic Listening

After controlling for hearing status there were no significant group differences in number of correct answers ($F(1, 75) = 1.12$, $p = 0.29$). The same applied for laterality indexes and homonyms. These results are presented in Table 4. However, the errors significantly differed between groups after controlling for PTA values [it is necessary to remind that according to the standard DL methodology, errors are defined as any answer not matching the applied stimuli. For instance if the syllables “BA-DA” were presented respectively to right and left-ear and the participants said “TA”, that will be considered a real error]. A closer analysis to these data showed that errors contained real errors but also several omissions. It turned out that many participants did not emit any answer in several trials. For this reason, we decided to calculate the total amount of errors and then, divided it into real errors and omissions. As depicted in Figure 1, omissions increased proportionally from NF to FL condition. In the NF condition almost all type of incorrect answers were real errors. Percentage of errors varies from 22.2% for the YO to 33.3% in the OO group. In FR condition, real errors decreased in both groups at expense of an increment in omissions. The percentage of total errors committed in the FR condition rises to 30.5% for YO and to 37.5% for OO. In the FL condition, again we observed an increment in omissions and in the total number of errors, especially for the YO group. This time, the percentage of total errors reaches 36.1% for YO and 38.8% for OO.

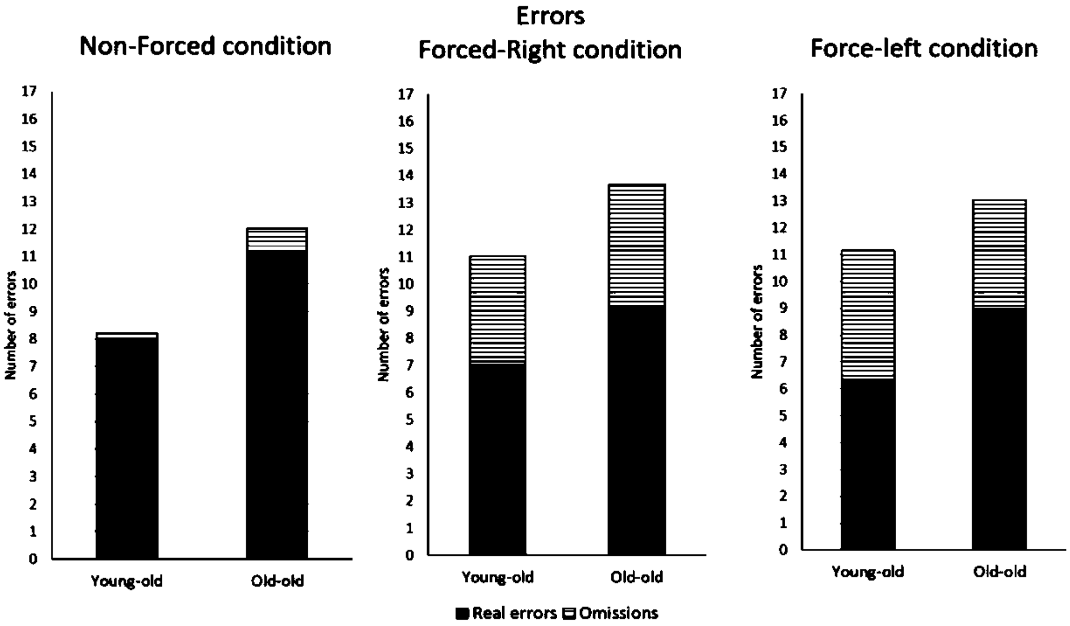

Figure 1. Dichotic listening results for errors by condition and age group.
Stacked bars show real errors in solid color and omitted responses in lined pattern.

Table 4 Dichotic Listening means (*M*) and standard deviations (*SD*).

	NON-FORCED CONDITION			**FORCED-RIGHT CONDITION**			**FORCED-LEFT CONDITION**		
	Correct responses			**Correct responses**			**Correct responses**		
	Right Ear *M* (*SD*)		**Left Ear** *M* (*SD*)	**Right Ear** *M* (*SD*)		**Left Ear** *M* (*SD*)	**Right Ear** *M* (*SD*)		**Left Ear** *M* (*SD*)
Young-Old	13.0 (3.2)		9.0 (3.1)	13.2 (4.8)		7.5 (2.8)	10.7 (4.6)		8.7 (3.7)
Old-Old	10.4 (3.8)		7.9 (3.4)	11.2 (4.9)		7.0 (3.6)	9.2 (5.0)		9.0 (4.2)
		Laterality index			**Laterality Index**			**Laterality Index**	
		M **(*SD*)**			***M*** **(*SD*)**			***M*** **(*SD*)**	
Young-Old		18.2 (22.2)			25.0 (26.9)			9.5 (27.6)	
Old-Old		14.0 (30.1)			23.4 (34.7)			3.4 (36.8)	
		Homonyms			**Homonyms**			**Homonyms**	
		M **(*SD*)**			***M*** **(*SD*)**			***M*** **(*SD*)**	
Young-Old		4.7 (1.1)			3.9 (1.9)			3.8 (1.8)	
Old-Old		4.2 (1.2)			3.6 (1.4)			3.7 (2.2)	
		Errors			**Errors**			**Errors**	
	Total ***M*** **(*SD*)**	***Real*** ***M*** **(*SD*)**	***Omissions*** ***M*** **(*SD*)**	***Total*** ***M*** **(*SD*)**	***Real*** ***M*** **(*SD*)**	***Omissions*** ***M*** **(*SD*)**	***Total*** ***M*** **(*SD*)**	***Real*** ***M*** **(*SD*)**	***Omissions*** ***M*** **(*SD*)**
Young-Old	8.2 (3.5)	8.0 (3.6)***	0.2 (0.6)	11.0 (6.3)	7.0 (3.9)*	4.0 (6.1)	11.2 (7.1)	6.3 (3.9)*	4.8 (6.8)
Old-Old	11.8 (4.9)	11.1 (3.7)	0.9 (2.2)	13.7 (7.5)	9.2 (4.6)	4.5 (5.8)	13.3 (6.6)	9.0 (4.9)	4.1 (5.1)

Note: All significant group differences presented are true after controlling for hearing status are denoted by: * = $p < 0.05$; ***= $p < 0.001$

Bilateral gait outcomes (see Table 5)

Mean values: *Step length* showed a significant main effect for Condition and Group and a significant interaction between Condition X Group. Tests for simple main effects showed that group differences were present across all conditions with constant higher values for the YO group. However, when we controlled for hearing status the interaction was no longer significant, though the effect of Condition and Group remained. On *Gait speed*, there was a main effect of Condition and Group and a significant interaction. After controlling for hearing, results were not altered Again the YO group displayed higher values than the OO group. For *Step width* no main effect of Condition or interaction with Group were found. Though, a main effect of Group was observed which was removed after controlling for PTA values in which the OO group presented wider step widths than the YO group. Finally, results for *Stride length* showed a main effect of Condition and Group but no interaction. Controlling for PTA values did not remove the significant effects in which the YO group presented higher values.

CoV values: There were limited significant effects on variability of gait. For step length, a significant main effect of Condition and Group were found but no interactions. The effect of Group turned non-significant after controlling for hearing status. The other significant result found on CoVs existed for gait speed in which the mixed ANOVA revealed only a main effect of Condition. This finding remained significant after controlling for hearing status.

Table 5. Results for bilateral gait parameters

	CONDITION									
	Baseline		**Non-Forced**		**Forced-Right**		**Forced-Left**			
	Y-O	O-O	Y-O	O-O	Y-O	O-O	Y-O	O-O	RMANOVA, *p*	ANCOVA, *p*
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	Condition/Interac./Group	Interac./Group/PTA
Mean										
Step length	67.5 (6.0)	61.7 (8.1)	65.0 (6.1)	58.1 (9.1)	63.6 (6.2)	56.0 (9.3)	63.7 (6.0)	56.0 (9.3)	**0.001**/ **0.047**/ **0.001**	NS / **0.023** / **0.001**
Gait speed	1.2 (0.1)	1.1 (0.2)	1.0 (0.2)	1.0 (0.2)	1.1 (0.2)	0.9 (0.2)	1.1 (0.2)	0.9 (0.2)	**0.001/ 0.001/ 0.001**	† / **0.034** / **0.003**
Step width	8.1 (2.7)	9.5 (2.2)	8.4 (2.4)	9.8 (2.4)	8.3 (2.5)	10.3 (4.6)	8.5 (2.4)	10.3 (3.9)	NS / NS / **0.004**	NS / NS / **0.003**
Stride length	138.0(14.0)	124.9(16.0)	132.3(13.1)	118.5(17.9)	130.0(13.5)	113.0(19.0)	130.0(12.1)	113.6(18)	**0.001**/ NS / **0.001**	NS / **0.011** / **0.001**
CoV (%)										
Step length	5.1 (2.8)	6.1 (4.1)	5.4 (2.8)	7.1 (3.8)	5.4 (3.8)	9.1 (5.6)	5.4 (3.3)	8.4 (5.1)	**0.01** / NS / **0.001**	NS / NS / **0.002**
Gait speed	4.6 (3.4)	6.2 (5.6)	6.4 (4.8)	6.9 (4.4)	6.5 (7.7)	11.0(14.7)	6.4 (7.4)	9.5 (13.1)	0.034 / NS / NS	NS / NS / NS
Step width	76.5(39.0)	75.8(29.2)	81.8(31.8)	71.8(23.8)	87.1(33.6)	79.9(29.9)	82.4(32.7)	79.3(32.9)	NS / NS / NS	NS / NS / NS
Stride length	8.9 (6.4)	7.4 (8.8)	10.0 (9.0)	10.7(12.1)	10.0(10.3)	9.4 (8.6)	10.6 (8.9)	9.1 (8.7)	NS / NS / NS	NS / NS / NS

Note: Interaction marked with † refer to = Condition X Group *p* = 0.049. Units for Step length, Step width and Stride length = cm.; units for Gait speed = m/sec

Abbreviations: Y-O = young-old group; O-O = old-old group; *M* = mean; *SD* = standard deviation; RMANOVA = repeated measures analysis of variance; ANCOVA = Analysis of covariance; CoV = Coefficient of Variation; Interac. = Interactions; PTA = worst Pure Tone Audiometry values; NS = Non Significant

CoV = Calculated with the formula: [mean/ SD] x 100%

Lateralized gait outcomes (see Table 6)

Mean values.

<u>Step length</u> showed a main effect of Condition (*F* (3, 120.06) = 36.52, $p < .001$), Group (*F* (1, 76) = 16.31, $p < .001$; higher values for the YO group) and a significant interaction for Condition X Group (*F* (3, 120.06) = 3.67, $p < .05$). However, controlling for hearing status on these analyses affected the results for Group (*F* (1, 75) = 3.58, $p = .06$) as well as the interaction Condition X Group (*F* (3, 83.35) = 0.89, $p = .36$) which no longer were significant.

<u>Gait speed</u> showed a main effect of Condition (*F* (3, 166.69) = 62.82, $p < .001$) and Group (*F* (1, 76) = 17.9, $p < .001$; higher values for the YO group). No significant main effect of Foot (*F* (1, 76) = 16.31, $p < .001$) or any significant interaction existed. Controlling for hearing status did not change these results. Nonetheless, there was a significant three-way interaction "Condition X Foot X Group" (*F* (3, 85.63) = 4.01, $p < .05$) after controlling for hearing status. Follow-up pairwise comparisons demonstrated that significant group differences existed for right $p < 0.05$ and left foot $p < 0.01$ across conditions. The YO group displayed a mean of 1.095 (m/s) for right foot, while the OO group presented a mean of 0.992 (m/s). As for the left foot, the mean speed displayed for YO was 1.101 (m/s) and 0.983 (m/s) for the OO group. Further scrutiny of the three-way interaction showed that the Non-Forced condition was a challenging situation for the OO group who displayed slower speed on the left foot (0.99 m/s) as compared to their right foot (1.03 m/s).

<u>Step width</u> showed only a significant main effect of Foot (*F* (1, 76) = 14.1, $p < .001$) and Group (*F* (1, 76) = 7.8, $p < .01$; higher values for the OO group). When controlling for hearing the main effect of Foot remained unchanged but not that of Group (*F* (1, 75) = 1.34, $p = .25$). These data showed that right foot presents wider values in both groups (YO = 9.1 cm; OO = 9.8 cm) as compared to the left side (YO = 8.4 cm; OO = 9.2 cm). It is important to

remind that step width for each limb is calculated from the lateral displacement of the specific foot based on its previous position.

<u>*Stride length*</u>, only significant main effects for Condition (*F* (3, 167.79) = 59.01, *p* < .001) and Group (*F* (1, 76) = 19.7, *p* < .001; higher values for the YO group) existed. Controlling for PTA values did not affect these results.

CoV values. Results of CoV data show limited significant results. In step length, a main effect of Condition (*F* (3, 143.44) = 4.65, *p* < .05) and Group (*F* (1, 76) = 11.24, *p* < .001) were found, but effects disappeared after controlling for hearing status. The same applies for gait speed. As for variability in step width, we did not find significant effects (see Table 5). The only significant result on CoV relates to stride length, as this variable was the only one showing a main effect of Foot (*F* (1, 76) = 5.65, *p* < .05), even after controlling for hearing status (*F* (1, 75) = 5.76, *p* < .05). These data suggest higher variability on stride length of the right limb in both groups, especially during the FR condition. Changes in CoV are not straightforward since increment of variability did not followed level of attentional difficulty of the conditions.

Table 6 Mean and Standard deviations for gait parameters by foot expressed in mean values and coefficients of variation (CoV).

Gait variables	CONDITIONS									
	Baseline		**Non-Forced**		**Forced-Right**		**Forced-Left**			
	Y-O	O-O	Y-O	O-O	Y-O	O-O	Y-O	O-O	Two-way ANOVA, *p*	Two-way ANCOVA, *p*
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	Condition/Foot/Inter/Group	Foot/Inter/Group/PTA
Mean										
Step length R	65.9 (12.2)	61.6 (8.2)	65.0 (6.5)	58.1 (9.6)	63.4 (6.6)	55.6 (9.6)	63.6 (6.0)	55.7 (9.7)		
Step length L	67.4 (6.1)	61.8 (8.0)	65.0 (5.8)	58.3 (8.7)	63.8 (5.8)	56.3 (9.1)	63.8 (6.0)	56.1 (9.1)	**0.001**/ NS/ **0.038**/ **0.001**	NS /NS / NS / **0.002**
Gait speed R	1.2 (0.1)	1.1 (0.2)	**1.1 (0.1)**	**1.0 (0.3)**	1.1 (0.2)	0.9 (0.2)	1.1 (0.2)	0.9 (0.2)		
Gait speed L	1.2 (0.1)	1.1 (0.2)	**1.1 (0.2)**	**0.9 (0.2)**	1.1 (0.2)	0.9 (0.2)	1.1 (0.2)	1.0 (0.2)	**0.001**/ NS / NS/ **0.001**	NS / † / **0.01** / **0.001**
Step width R	8.3 (3.5)	9.9 (2.2)	8.6 (2.5)	9.6 (4.2)	8.6 (2.8)	10.5 (4.4)	8.9 (2.7)	10.8 (3.7)		
Step width L	7.6 (2.6)	9.0 (2.8)	8.1 (2.5)	9.5 (3.1)	8.1 (2.2)	10.1 (4.9)	8.1 (2.1)	9.9 (4.1)	NS / **0.001**/ NS/ **0.007**	**0.001**/ NS / NS/ **0.001**
Stride length R	137.5(12.7)	125.1(16.1)	132.1(12.4)	118.8(18.0)	130.7(14.4)	113.2(19.0)	130.3(12.7)	113.8(18.2)		
Stride length L	138.3(15.3)	124.7(16.4)	132.4(14.0)	118.1(18.1)	129.3(12.9)	112.9(19.1)	129.6(12.0)	113.5(17.8)	**0.001** / NS / NS/ **0.001**	NS /NS /**0.01** /**0.001**
CoV (%)										
Step length R	4.8 (3.0)	6.1 (3.8)	4.7 (2.4)	6.8 (3.7)	5.2 (3.5)	8.6 (6.1)	5.2 (2.5)	8.0 (5.4)		
Step length L	4.7 (3.2)	5.7 (5.0)	5.4 (3.5)	6.8 (4.1)	5.2 (4.0)	8.7 (5.7)	5.3 (4.1)	8.2 (5.1)	**0.013** / NS/ NS / **0.002**	NS /NS /NS / **0.001**
Gait speed R	4.7 (4.3)	6.5 (6.1)	6.6 (5.1)	6.7 (4.7)	6.3 (8.0)	10.4 (15.3)	6.4 (7.1)	9.8 (14.2)		
Gait speed L	4.3 (2.5)	6.0 (5.6)	6.4 (4.8)	7.1 (4.4)	6.5 (7.7)	11.4 (14.6)	6.4 (7.7)	9.5 (13.1)	**0.04** / NS / NS / NS	NS /NS /NS / NS

Step width R	78.1(33.0)	69.1(24.5)	73.8(23.0)	65.6(19.2)	83.6(31.4)	73.7(23.4)	77.3(29.3)	72.3(28.1)		
Step width L	71.1(34.9)	77.1(34.2)	77.5(32.0)	71.2(25.1)	85.3(35.6)	76.0(26.8)	78.3(28.6)	76.9(29.0)	NS / NS / NS / NS	NS /NS /NS / NS
Stride length R	7.6 (7.8)	7.1 (7.8)	9.2 (8.9)	11.2(13.7)	10.8 (11.7)	10.0(10.9)	10.8 (9.9)	8.8 (9.1)		
Stride length L	7.5 (6.7)	6.3 (9.0)	9.4 (10.9)	9.1 (9.6)	7.9 (9.4)	7.8 (6.1)	8.9 (8.9)	8.4 (8.4)	NS / **0.02** / NS/ NS	**0.02** /NS /NS / NS

Note: Interactions marked with † refer to = Condition X Foot X Group $p < 0.05$. Units for Step length, Step width and Stride length = cm.; units for Gait speed = m/sec

Abbreviations: Y-O = young-old group; O-O = old-old group; M = mean; SD = standard deviation; RMANOVA = repeated measures analysis of variance; ANCOVA = Analysis of covariance; CoV = Coefficient of Variation; Interac. = Interactions; PTA = worst Pure Tone Audiometry values; NS = Non Significant

CoV = Calculated with the formula: [mean/ SD] x 100%

Associations between DL performance and gait parameters

Pearson's correlations coefficients are shown in Table 7. In these analyses, we examined the associations between correct numbers of answers (i.e., answers matching the applied stimuli) for right or left ear and gait outcomes from right and left foot separately. Results demonstrated that right ear answers across conditions were significantly associated with gait results in the 3 DL conditions, while correlations with left-ear answers were only found in the NF condition.

Correlations with mean values of gait and right-ear answers. Table 7 shows that right ear answers had the higher number of correlations with gait parameters across conditions. Mostly, right ear answers were significantly related with gait measures bilaterally, indicating that as number of responses from right ear increases the higher are mean values for gait. Though, few mean values showed lateralized associations.

Correlations with CoV values of gait: Significant associations between matching answers and CoVs in gait parameters were found in the NF and FL condition. Right ear answers were negatively associated with bilateral CoVs of step length and speed in FL condition. In contrast, left ear answers were positively associated to bilateral CoVs of stride length in the NF condition. These latter correlations were the highest encountered showing $r = 0.45$ ($p < 0.01$) for right foot and $r = 0.37$ ($p < 0.01$) for left foot. All-in-all, data suggest that higher number of right ear answers when focus of attention is intended to the left ear decrease CoVs in speed and step length, while higher left ear responses in NF condition are linked to higher variability in stride length.

Table 7. Pearson correlations between correct matched answers by ear and lateralized gait outcomes per DL condition

	Right ear answers			Left ear answers
Gait parameters	Non-Forced	Forced-Right	Forced-Left	Non-Forced
Right foot				
Step length				
mean	NS	NS	0.29 *	NS
CoV	NS	NS	-0.37**	NS
Stride length				
mean	NS	0.23*	0.27*	NS
CoV	NS	NS	NS	0.45**
Gait speed				
mean	NS	0.26*	0.35**	NS
CoV	NS	NS	-0.23*	NS
Left foot				
Step length				
mean	0.27*	0.24*	0.31**	NS
CoV	NS	NS	-0.37**	NS
Stride length				
mean	NS	NS	0.27*	NS
CoV	NS	NS	NS	0.37**
Gait speed				
mean	0.25*	0.23*	0.35**	NS
CoV	NS	NS	-0.25*	NS

Note: Only significant correlations are presented. * $p < 0.05$, ** $p < 0.01$. N.S = non significant results

Discussion

The first main finding of the present investigation indicates that lateralized focus of attention alters asymmetrically in three of the gait parameters evaluated in healthy older adults. These asymmetries were observed on step width, gait speed and variability of stride length.

Results for step width demonstrated that right foot displayed higher values than left foot in both groups and in all conditions including baseline. This finding suggests that asymmetries in step width are not only related to the dual-task paradigm but are an intrinsic characteristic of older adults. The asymmetries encountered in the baseline condition should be regarded as a result of the overground methodology employed in our study. Usually, subjects are required to walk within a specific short distance and not during a time period. These results agree with earlier data showing that step width differentiates between young and older adults (Hamacher, Singh, Van Dieen, Heller, & Taylor, 2011). Even though, no significant interactions were found, we observed that step width asymmetries increased during DL execution, particularly for OO subjects during the forced-left condition. In this condition, the OO group presented a between-feet difference of almost 1 cm (10.8 cm for left foot vs 9.9 cm for right foot) while their amount of correct responses from right and left ear was almost equal. These data show the difficulty from the OO participants to focus and/or process left side stimuli, which results in enlarged step width being particularly higher for the right foot.

The next finding showing the effects of lateralized control of attention was observed on gait speed in the NF condition. This time, the OO group emitted a higher number of right-ear answers while they demonstrated slower speed with left foot. Though, these participants also had the highest number of real errors in all DL conditions. All together, these data suggest that the NF condition is a challenging one for the OO group due to increased uncertainty on attentional focus and perceptual constraints. Thus, it appears that the symmetry of walking speed is sensitive to hesitation in deciding which source of information has to be attended. The last asymmetric finding was that of increased stride length variability in both groups, specifically on their right foot. It is plausible that higher variability in this measure occurred due to reductions in rhythmicity caused by other gait asymmetries (LaRoche, Cook, & Mackala, 2012).

Taken together the above findings, it is evident that asymmetric effects occurred mostly on the right limb. Our interpretation is that our paradigm exerts a more accentuated effect on right foot due to higher involvement of the left hemisphere. In spite of the lateralized focus of attention required on DL to both left and right ear, DL remains a language task that relies on the ultimate activation of left hemisphere to process the auditory signal. Increased loading on left hemisphere may destabilize mechanisms associated with contralateral control of lower limbs' movements.

Possible mechanisms underlying the effect of DL on gait

The asymmetries encountered showed that DL perturbs asymmetrically "pace" measures of gait. Verghese et al (2007) proposed that velocity and length measures represent the "pace" aspect of gait, which is associated with executive functioning. Our data corroborated this assertion as DL relies not only on focusing attention to one side, but on mechanisms necessary for inhibiting the competing stimulus. The fact that DL disturbs these parameters asymmetrically can be understand as overloading of common brain areas necessary for accomplishing both tasks, which we suggest are related to frontal lobe circuitry. Although, the mechanisms of how the brain operates under dual-tasking remains an open question, it is plausible that proper wiring of frontal areas through integrity of corpus callosum (CC) is behind the observed asymmetries. The age-related thinning of CC has been proved central for DL performance (Westerhausen et al., 2015) and it also has been reported as important for gait and balance (Bhadelia et al., 2009)). In addition, the CC might also play a main role in the context of dual-tasking where complex sensorimotor integration is required for maintenance of balance and integration of visual and proprioceptive cues. Information about the integrity of CC in our participants should have clarified this matter and future research may address this issue.

Hearing status as moderator of attention and gait disturbances in dual-tasking

The second goal of the present study was to evaluate the effects of hearing loss on DL execution and gait. As expected, hearing loss hampered DL performance, as controlling for hearing status ruled out significant group differences in this test. However, the neuropsychological results demonstrated that both groups differed in cognitive capacities, notably in those assessing similar functions to the DL, such as the Stroop test and the TMT that evaluate executive functions and inhibition.

Hearing loss also modulated the effects on gait during dual-tasking. The moderating effects of hearing loss were first evaluated in bilateral gait measures, that is, when values for both limbs were taken together. Prior to controlling for hearing loss, we found significant group differences in the mean of all gait parameters including one variability measure on step length, which agrees with previous investigations (Hollman et al., 2011). However, after controlling for hearing status, many of the significant effects and interactions were partialled out. Also, after controlling for hearing loss one of the asymmetric effects (i.e., gait speed) was encountered, which implies that hearing loss masked this asymmetry. These findings suggest that hearing status in older adults, moderates result of the dual-task paradigm. These data need to be assembled to previous research showing that moderate to greater hearing impairments, i.e. PTA > 40 dB, are associated with falls and risk of developing frailty (Kamil et al., 2016). Our data suggest that even milder levels of hearing loss (25dB - 40 dB) in healthy older adults, altered spatiotemporal measures of gait. As previous data have highlighted, age-related hearing loss is associated with falls and slower gait speed. In our study, group effects on gait speed remained after controlling for hearing status. However, the means of step width and step length seemed to be sensitive to the effects of hearing status as significant group differences disappeared after controlling for PTA values.

Notwithstanding, in spite of finding that hearing status modulates gait and cognitive results, caution is required in the interpretation of these data as it is not possible to isolate the age-related variance from the hearing-related variance. The issue of whether controlling for degree of hearing loss helps or hinders our understanding of an age-related phenomenon has been addressed in the literature previously (Martin, Ellsworth, & Cranford, 1991). Some authors warns against indiscriminate use of statistical techniques to control for hearing loss "*without careful consideration of theoretical foundations*" (Martin et al., 1991). In the present study, we have presented thoroughly a paradigm for lateralized auditory attention that relies, among many mechanisms, on the correct perceptual recognition of an auditory signal. We believe that even though we cannot assert that hearing loss is the only factor modulating the reported effects on gait and cognition, it would also be biased to deny its role to accomplish the present experimental situation. In line with earlier research pointing to associations between walking difficulty and hearing acuity in age-adjusted models (Viljanen et al., 2009) our findings suggest that hearing loss cannot be underestimated as an important factor modulating group differences on gait asymmetries.

Association between DL conditions and gait

Overall, right ear answers had the most significant correlations with gait measurements, especially during the Forced-Left situation. All coefficients of correlation were rather modest, even if all of them were significant. Still, these data are suggestive as number of correlations were scarce in NF condition and they increase gradually in the FR and became spread in the FL condition. All correlations of right-ear answers with mean values of gait were positive while correlations with CoVs were negative, indicating that correct right-ear responses are related to larger mean values and lower gait variability in all participants. According to the standard procedure, any answer matching an applied stimuli to right or left ear is a correct answer. Attending to right-ear when the contrary is required can be regarded as maladaptive and an indication of difficulties with top-down attentional control, our interpretation is that increased number of right-ear answers secure participants to preserve a safe walk. Even though older adults experience some degree of hearing loss, they have developed through a long life a good capacity to process information from right ear. This peculiarity allows a compensatory strategy to avoid insecure walking as processing right-side information is not related to increased gait variability, which leads to deteriorated stepping control and falls in older adults (Dingwell, Salinas, & Cusumano, 2017). Thus, limitations in attending left-ear information help older adults to cope with sensory loss and cognitive demands during the challenging situation of walking, listening and talking. We suggest that an automatic adaptation exists in right-handed older persons to avoid listening to the left side during dual-tasking and avoid the risk of falling.

Finally, the correlations observed for left ear answers were probably the most clear-cut associations as they were only present on CoVs of both feet in stride length during the NF condition. These correlations were positive and somewhat stronger than the previous set of results, suggesting that when participants report left-ear stimuli in the NF condition stride length variability increases significantly. Accordingly, these data indicate that by attending left-ear information the risk of a fall increases since stride length variability has been found to be a good predictor of injurious falls (Verghese, Holtzer, Lipton, & Wang, 2009).

Limitations of the study

Although, we wanted to understand the effects of our paradigm in naive subjects the lack of single task results for DL in our investigation is a limitation. No correlations with the errors are presented, which is another limitation of the study. The reason for not including these correlations was the reduced and variable number of errors per subject and condition, which is disproportional to the available gait data. Another potential limitation is the difference in time concerning the baseline trial for walking (1 min.) vs the dual-task conditions (3 min.). It can be argued that comparisons between conditions and the baseline are not equivalent, as they do not match exact number of walking cycles. However, according to guidelines for appropriate evaluation of spatiotemporal analysis of gait in older populations there should be a minimum of 3 consecutive gait cycles by limb to obtain correct evaluations (Kressig & Beauchet, 2006). Thus, our participants performed between 30 and 50 gait cycles during the 1 minute baseline trial, which allows calculation of appropriate estimates of spatiotemporal gait parameters. Future investigations should assess whether results are affected by equal number of gait cycles.

Conclusions

The present study demonstrates that in right-handed older adults lateralized auditory attention affects gait asymmetrically. It also became evident that hearing status ranging from normal to mild hearing loss modulates the effects of focus of auditory attention on gait. Finally, we showed that focus of attention to the right side do not compromise gait. It can even be argued that attending to the right side is beneficial, as participants displayed larger and wider steps, larger strides and less gait variability while listening to right-ear stimuli. On the contrary, attending to left-side stimuli increases stride length variability. In summary, the present investigation demonstrates that DL is a convenient test to evaluate the interplay of gait, hearing and attentional control during overground walking and should be employed in future work as part of multifactorial analysis. For instance, future studies may address the neural correlates of the reported asymmetries as well as gender effects on lateralized gait disturbances. The issue of asymmetries on left-handed participants is warranted as we only examined right-handed persons. Correspondingly, application of the dual-task paradigm in geriatric patient populations affected by cognitive dysfunctions would be highly valuable as information from patients will put in perspective the findings reported in the present investigation.

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Disclosure statement

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Highlights

- Lateralized auditory attention affects gait asymmetrically.
- Asymmetric effects are demonstrated in healthy right-handed older adults.
- Age-related hearing loss modulates the effects of lateralized attention on gait.
- Focus of attention to the right side do not compromise gait.
- Attending left-side stimuli increases stride length variability.