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Gradient impact of cognitive decline in unilateral vestibular hypofunction after rehabilitation: preliminary findings

Alessandro Micarelli[1,2] · Andrea Viziano[1] · Ernesto Bruno[1] · Elisa Micarelli[3] · Ivan Augimeri[2] · Marco Alessandrini[1]

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Abstract

Purpose Considering recent advances in central cognitive- and age-related processing interfering with balance and sensory reweighting in uncompensated vestibular disorders, purpose of this study is to highlight the vestibular rehabilitation (VR) outcomes in a population of older adults and age-matched mild cognitive impairment (MCI) patients, both affected by unilateral vestibular hypofunction (UVH) and undergoing VR.

Methods Vestibulo-ocular reflex (VOR), postural sway examination (respectively, performed by video head impulse test and static posturography) and dizziness-related and quality-of-life scores were collected in 12 UVH MCI individuals ≥ 55 years and 12 matched UVH older adults with age-appropriate cognitive function—cognitively evaluated by means of Mini-Mental State Examination (MMSE) and Alzheimer's Disease Assessment Scale—before and after a VR protocol.

Results A significant post-treatment reduction in surface, length and power spectra (PS) values within low-frequency domain and an improvement in performance measures were recorded in both groups. Moreover, the VR protocol highlighted—when comparing pre-/post-treatment differences (Δ)—a significant (i) increase in Δ VOR gain; (ii) decrease in Δ surface and length and (iii) increase in Δ PS within low-frequency domain in older adults when compared to MCI patients. Positive correlations were found between MMSE and Δ Dynamic Gait Index, Δ surface and Δ PS within low-frequency domain when treating patients as 'a continuum' along the cognitive decline.

Conclusions Present pilot findings suggest that the cognitive domain insight in older adults scheduled for VR protocols may positively impact on disability consequences.

Keywords Vestibular rehabilitation · Vestibular hypofunction · Cognitive decline · Mild cognitive impairment · Aging

Introduction

The mainstay of treatment for vestibular weakness is vestibular rehabilitation (VR) which has been found to be effective for improving dizziness, quality of life, and balance control [1]. In particular, VR uses central neuroplasticity mechanisms (adaptation, habituation, and substitution) to increase static and dynamic postural stability and improve visuo-vestibular interactions in situations that generate conflicting sensory information [2]. Moreover, it may improve static and dynamic balance and gait, reducing symptoms of dizziness and comorbid depression and anxiety, and ultimately resulting in increased self-confidence and quality of life in sufferers [3]. However, many factors have been seen to possibly affect the outcome of vestibular rehabilitation, including incorrect performance of the exercises and the need for active efforts and the interest of the patient [4].

Previous studies demonstrated that older adults—with or without previous vestibular disorders—have reduced multisensory function [5–9] and that age-related visual, proprioceptive, or vestibular loss could make sensory integration for balance more difficult via a deranged cognitive-related sensory signal processing [5, 7–10].

In this vision, although recent protocols tried to clarify how central cognitive- and age-related processing may interfere with balance [8, 9] and sensory reweighting in

✉ Alessandro Micarelli
alessandromicarelli@yahoo.it

1 Department of Clinical Sciences and Translational Medicine, University of Rome Tor Vergata, Via Montpellier, 1, E sud Tower, 00133 Rome, Italy

2 ITER Center for Balance and Rehabilitation Research, Rome, Italy

3 Department of Biology, University of Rome Tor Vergata, Rome, Italy

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uncompensated vestibular disorders [7], the link between vestibular dysfunction and vestibular rehabilitation outcomes along cognitive decline still remains unclear. Thus, considering the emerging interest towards central neuroplasticity mechanisms involved in VR and the link between age-related vestibular dysfunction and cognitive decline, the purpose of the present study is to highlight the rehabilitative outcomes in a population of older adults and age-matched mild cognitive impairment (MCI) patients, both affected by UVH and undergoing VR.

Materials and methods

Subjects

UVH MCI subjects participating in VR protocol were extracted after their enrolment and otoneurological evaluation [7] in the local longitudinal cohort study of aging performed by the UNITER Center for Rehabilitation, a regional institutional interdisciplinary disorder clinic. The inclusion criteria for MCI were as follows: (1) age ≥ 55 years; (2) diagnosis of MCI; (3) Mini-Mental State Exam (MMSE) score ≥ 11; (4) fluency in Italian; and (5) ability to obtain informed consent from the participant or legally authorized representatives [7]. The National Institute on Aging/Alzheimer's Association diagnostic criteria were used for the diagnosis of MCI and applied by a skilled clinician [11, 12]. The MMSE cut-off score was chosen based on selective criteria for moderate-to-severe cognitive impairment [13]. Data from 12 age-, gender- and education-matched UVH older adults with age-appropriate cognitive function—serving as control group—were extracted from the Tor Vergata University Hospital database that previously evaluated a cross-sectional sample of participants undergoing vestibular testing [7]. The severity of dementia-related orientation behavior was also graded according to the Alzheimer's Disease Assessment Scale (ADAS-cog) orientation subscale in both groups [14].

According to accepted criteria [2], the diagnosis of chronic UVH was achieved by responses to bithermal water caloric irrigations, with at least 25% reduced vestibular response on one side when calculated by means of Jongkees' formula [15] at least 3 months after the onset of symptoms.

Individuals were excluded if they were unable to understand the examination procedures, or were unable to participate in study procedures because of physical conditions, such as blindness, poor neck range of motion, or cervical spine instability. Demographic information (age, sex, and education) was extracted from the patients' charts. Education was classified as less than 4, 5–7, 8–13 or higher than 14 years. Clinical history of all study subjects did not record falls, or relevant cardiovascular, metabolic, rheumatologic, orthopedic or other neurological conditions [8]. The study was approved by the Regional Ethical Committee Review Board, it adhered to the principles of the Declaration of Helsinki and all the participants provided written informed consent after receiving a detailed explanation of the study.

After a thorough clinical otoneurological examination [16], all UVH subjects underwent 1 week before and 1 week after the VR protocol the following.

Otoneurological testing

Video head impulse testing (vHIT)

For vHIT measurements the EyeSeeCam™ System and the technique proposed in previous studies were used [16, 17]. The vHIT results were classified as abnormal if two conditions were met: abnormal gain according to the calculated normative data and presence of refixation saccades (revealed by visual inspection, according to Blodow et al. [17]). With the manufacturer's software (OtoAccess™), both side median (med) values recorded at 60 ms were extracted on .xls files for raw analysis. In line with previous procedures [16–18], diagnosis of UVH was confirmed in the present cohort in case of gain below 0.83 and 0.84 for right and left side, respectively, calculated as the lower cut-off value of the gain-reference range [$\text{mean}_{\text{normal}} \pm 2$ (standard deviations; SD) equal to 0.91 ± 2 (0.04) and 0.90 ± 2 (0.03) for right and left side, respectively], incorporating 95% of healthy population, age- and gender-matched with the current population of patients [16–18] and including 153 normal volunteers in our laboratory [7].

Static posturography testing (SPT)

Each patient was instructed to keep an upright position on a standardized platform for static posturography (EDM Euroclinic®). The recording period was 60 s for each test (eyes closed or opened while standing on the stiff platform) and the sampling frequency in the time domain was 25 Hz [16, 18, 19]. The center of pressure was monitored, while performing the test. The posturographic parameters considered in our study were the trace length (length), the surface of the ellipse of confidence (surface) and the fast Fourier transform (FFT) elaboration of oscillations on both the X (right-left) and Y (forward–backward) planes [16, 18, 19]. FFT elaborations of time-domain oscillations signals (X and Y) were gained through a core function implemented on Matlab space [7]. Spectral values (power spectra, PS) of body oscillations were quantified on an .xls file, for every frequency from 0.0122 to 4.9927 Hz [7, 16, 18, 19]. As in previous experiences [7, 16, 18, 19], we subdivided the frequency spectrum into three groups: 0.0122–0.6958 Hz (low-frequency interval); 0.708–0.9888 Hz (middle-frequency interval); 1.001–4.9927 Hz (high-frequency interval).

Within each group, the spectral intensity was determined by adding the relative PS and the group mean PS (±SD) [16, 18, 19]. Normative posturography and PS values, regarding 153 age- and gender-matched healthy volunteers (82 females, 71 males; mean age 74.8±4.6 years) are reported in previous study [7].

Self-report (SRM) and performance measure (PM)

1. The Italian Dizziness Handicap Inventory (DHI) version comprises 25 questions designed to assess a patient's functional (DHI-F; 9 questions), emotional (DHI-E; 9 questions) and physical (DHI-P; 7 questions) limitations on a three-point scale [20].
2. The activities-specific balance confidence scale (ABC) was used to record the patient's perceived level of balance confidence during 16 daily living activities ranging from 0 to 100% [21, 22].
3. The Dynamic Gait Index (DGI) examined a person's ability to perform various gait activities such as walking with head turns and avoiding obstacles [22]. The scale has eight items and each item is scored from 0 to 3 [21, 22].

Vestibular rehabilitation protocol

The execution of the exercises was personalized by the therapist according to the patient's symptoms, cognitive and functional disability. According to previous protocols [3, 22, 23], all chronic UVH patients were seen in the clinic twice a week for 4 weeks for 30–45 min and monitored for adherence. Between supervised sessions, patients followed a twice-daily home exercise program for a total of 30–40 min per day. The home exercise program included a combination of exercises, summarized as follows.

Adaptation exercises To improve gaze stability, subjects were initially asked to move their heads in yaw rotation while focusing on a stationary hand-held target, X1 viewing. They then progressed to X2 viewing, in which the target and the head rotated in equal and opposite yaw directions. Exercises were performed in horizontal and vertical planes 3 times a day for 1 min each.

Substitution exercises Patients with little or no vestibular function were taught to substitute their loss of vestibular function with visual and somatosensory inputs. For example, a patient might be instructed to fixate gaze during ambulation to stabilize walking and to decrease veering to the side, or to stand on a foam platform with eyes closed to keep their balance. Substitution exercises were modified to become increasingly more difficult as the patient improved.

Visual desensitization Disturbances that the patients experienced while performing their daily activities were determined. In patients reporting enhanced sensitivity or poor tolerance to self or visual motion, additional desensitization exercises were added.

Balance exercises Patients attempted to restore balance while switching between static (e.g., standing) and dynamic movements (e.g., walking) by altering visual, somatosensory and vestibular impulses.

The exercises were designed to be challenging during the training period, and different aspects of balance training were emphasized for different patients to provide individualization. Family involvement was achieved in order to support home rehabilitation protocol. Compliance was monitored using a calendar, which the patients or relatives filled out at home as they performed each exercise, and took back to the clinic each visit.

Data handling and statistical analysis

The Chi-square test was carried out to define associations between categorical factors and groups. Mean and standard deviations (SDs) of otoneurological, SRM/PM scores and neuropsychological measures were calculated in all groups.

In order to assess that data were of Gaussian distribution, D'Agostino K-squared normality and Levene's homoscedasticity test were applied (where the null hypothesis is that the data are normally and homogeneously distributed).

A within-subjects analysis of variance (ANOVA) was performed for each otoneurological and SRM/PM variable. Furthermore, a between-group ANOVA was performed for each pre-/post-treatment difference (Δ) in otoneurological and SRM/PM variables. Gender, age, neuropsychological measures, MCI disease duration (DD, in months), elapsing time (ET, in years) between UVH and MCI diagnosis were treated—where possible—as categorical and continuous predictors. The significant cut-off level (α) was set at a p value of 0.05. Bonferroni correction for multiple comparisons was used for the post hoc test of the significant main effects.

Then, considering the exploratory nature of the study and the homoscedasticity of pre-treatment vestibular weakness between the two groups of patients, a two-tailed Spearman's rank correlation was performed between significant Δ otoneurological scores, Δ SRM/PM scores and neuropsychological measures, considering UVH patients values as 'a continuum'. Thus, given the sample size of this group and the two-tailed nature of the test, a significant cut-off level (α) was set at a p value of 0.05 (STATISTICA 7 package for Windows).

Results

Subjects

Among 47 previously enrolled UVH patients, 12 affected by MCI (five males and seven females; mean age

72.5 ± 3.6 years) and 12 older adults (six males and six females; mean age 74.3 ± 4.7 years) were included in the VR protocol (Table 1). No patient from either group left the VR protocol ahead of time.

Otoneurological testing

Although no significant VOR gain within-subjects effect was found, the between-group analysis highlighted a significant ($p = 0.014$) increase in Δ VOR gain in older adults when compared with MCI subjects (Fig. 1; Table 2).

Post hoc comparison found a significant difference in both older adults and MCI surface and length values during both eyes closed ($p = 0.0041$, $p = 0.0035$ and $p = 0.0093$, $p = 0.0054$, respectively) and eyes opened ($p = 0.0078$, $p = 0.0066$ and $p = 0.0074$, $p = 0.0055$, respectively) conditions when comparing pre- and post-treatment measures (Table 3). However, when comparing Δ measures older adults demonstrated a significant decrease in surface during eyes closed condition ($p = 0.0094$) and length during both eyes closed ($p = 0.0094$) and eyes opened ($p = 0.011$) conditions with respect MCI patients (Table 2).

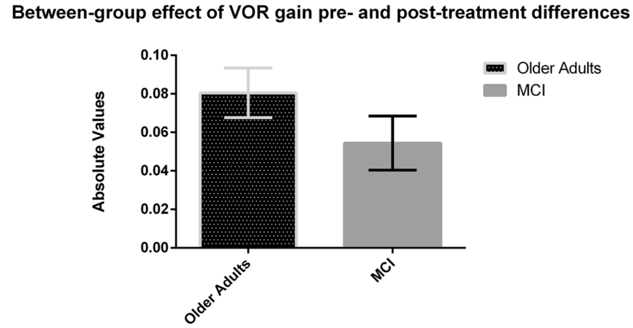

Fig. 1 Histogram representing mean and standard deviations of pre-/post-treatment vestibulo-ocular (VOR) gain differences and the significant changes between older adults and mild cognitive impairment unilateral vestibular hypofunction patients

In the field of FFT analysis, Bonferroni correction found significant post-treatment reduction of PS values in both eyes closed and eyes opened condition on X and Y planes in both UVH older adults ($p = 0.0087$, $p = 0.0063$, $p = 0.0046$, $p = 0.0039$, respectively) and MCI subjects ($p = 0.0094$, $p = 0.0086$, $p = 0.0042$, $p = 0.0038$, respectively) in the low-frequency interval (Table 3). However, the Δ PS

Table 1 Clinical and socio-demographic description of unilateral vestibular hypofunction (UVH) participants

	Older adults ($n = 12$)	MCI ($n = 12$)
Age (years)	74.3 ± 4.7	72.5 ± 3.6
Male	6	5
Female	6	7
Lesional side	R = 7	R = 6
	L = 5	L = 6
Pre-treatment VOR gain of affected side	0.63 ± 0.03	0.62 ± 0.03
Post-treatment VOR gain of affected side	0.71 ± 0.03	0.67 ± 0.02
ET (years)	16.5 ± 5.7	17.4 ± 4.9
DD (months)	–	23.5 ± 5
MMSE	28.1 ± 1.2	25.5 ± 1.4
ADAS-cog (orientation subscale)	7.2 ± 0.7	5 ± 0.9
Education level		
< 4 years	2	2
5–7 years	5	6
8–13 years	3	2
> 14 years	2	2
UVH etiology		
Neuronitis	7	8
AN	2	1
Previous petrous	1	2
Previous cochlear	1	1
Ramsay Hunt	1	–

Clinical and socio-demographic aspects of UVH older adults and mild cognitive impairment (MCI) participants. Time from diagnosis of MCI (disease duration), *DD* time from diagnosis of UVH (elapsing time), *ET* right, *R* left, *L* vestibulo-ocular reflex, *VOR* Mini-Mental State Exam, *MMSE* Alzheimer's Disease Assessment Scale orientation-related subscale, *ADAS-cog* acoustic neuroma, *AN* petrous surgery, *petrous* cochlear surgery, cochlear

Table 2 Significant between-group effect of main pre- and post-treatment differences in UVH older adults and mild cognitive impairment patients

	Older adults		MCI		Significance
	Mean	SD	Mean	SD	
PS LF CE X	2.36	0.79	1.21	0.51	$F(1, 11) = 12.761$, $p < 0.001$
PS LF CE Y	2.52	0.64	1.34	0.45	$F(1, 11) = 43.311$, $p < 0.001$
PS LF OE X	1.53	0.31	1.13	0.19	$F(1, 11) = 25.777$, $p < 0.001$
PS LF OE Y	1.33	0.2	1.08	0.14	$F(1, 11) = 12.553$, $p < 0.001$
Surface CE	588.38	161.07	207.41	91.39	$F(1, 11) = 44.759$, $p < 0.001$
Length OE	246.96	54.27	134.49	39.98	$F(1, 11) = 25.294$, $p < 0.001$
Length CE	299.7	49.29	131.49	38.41	$F(1, 11) = 91.013$, $p < 0.001$
VOR gain of affected side	0.08	0.01	0.05	0.01	$F(1, 11) = 33.878$, $p < 0.001$
DHI-E	9.83	2.48	6.5	1.93	$F(1, 11) = 12.791$, $p < 0.001$
DHI-F	9.66	2.8	6.83	1.33	$F(1, 11) = 8.0481$, $p < 0.001$
Total DHI	27.66	4.65	19.5	1.93	$F(1, 11) = 24.208$, $p < 0.001$
DGI	6.5	0.9	3.91	0.79	$F(1, 11) = 59.056$, $p < 0.001$
ABC	7.5	1.44	5.91	0.9	$F(1, 11) = 7.0533$, $p < 0.001$

Significant between-groups changes in main otoneurological, self-report and performance measures pre- and post-treatment differences in unilateral vestibular hypofunction (UVH) older adults and mild cognitive impairment (MCI) patients

Exact *p* values are given in the text

PS power spectra, *LF* low-frequency interval, *OE* opened eyes, *CE* closed eyes, *X* X plane, *Y* Y plane, *VOR* vestibular–ocular reflex, *DHI* Dizziness Handicap Inventory, *E* emotional, *F* functional, *DGI* Dynamic Gait Index, *ABC* activities-specific balance confidence scale, *SD* standard deviation

values in this interval was found significantly higher in both eyes closed and eyes opened condition on X and Y planes ($p = 0.018$, $p = 0.0094$ and $p = 0.011$, $p = 0.018$, respectively) in older adults when compared to MCI patients (Fig. 2; Table 2).

Neither within-subjects nor between-groups differences were found within the middle- and high-frequency intervals.

SRM and PM

Bonferroni correction found a significant post-treatment reduction in physical, emotional, functional and total DHI values in UVH older adults ($p = 0.0089$; $p = 0.0056$; $p = 0.0067$; $p = 0.0036$, respectively) and MCI patients ($p = 0.0048$; $p = 0.0036$; $p = 0.0032$; $p = 0.0011$, respectively) (Table 3). However, the Δ values in emotional, functional and total DHI were found significantly higher ($p = 0.012$, $p = 0.0019$ and $p = 0.0092$, respectively) in older adults when compared to MCI patients (Table 2).

Furthermore, a significant post hoc correction increase was found when comparing pre- and post-treatment DGI and ABC scores in UVH older adults ($p = 0.0027$ and $p = 0.0045$, respectively) and MCI ($p = 0.0056$ and $p = 0.0037$, respectively) patients, highlighting in both scales a significant increase of Δ values in older adults when compared to MCI patients ($p = 0.0087$ and $p = 0.017$, respectively) (Tables 2, 3).

When considering UVH patients values as 'a continuum', significant ($p < 0.05$) positive correlations were found between MMSE score and (i) Δ surface values during eyes closed condition ($r = 0.78$); (ii) Δ PS values during eyes closed condition on Y plane in the low-frequency interval ($r = 0.83$) and (iii) Δ DGI scores ($r = 0.75$) (Fig. 3).

Discussion

The first interesting finding in the present study is the significant post-treatment maximization effect of ipsilesional Δ VOR gain improvement found in the UVH older adults when compared with the MCI group (Fig. 1; Table 2), although its improvement was found to not be significant across both groups after the VR protocol. These results are in line with those dynamic visual acuity test changes indicating the development of compensatory mechanisms after vestibular impairment [24] and indicate for the first time cognitive decline as a factor possibly affecting the outcome of VR. Indeed, the purpose of VR is to improve the ability of the central nervous system to compensate for lesions or dysfunction in the sensory integration of vestibular, visual, and somatosensory signals [2, 3, 25]. Although the route through which these processes lead to symptom reduction is not fully elucidated, main learning principles include adaptation through sensory information and/or behavioral substitution (i.e., reweighing other sensory information) and habituation

Table 3 Pre- and post-treatment significant within-subjects effect of main measures in UVH older adults and mild cognitive impairment patients

	Older adults				Significance	MCI				Significance
	Pre-treatment		Post-treatment			Pre-treatment		Post-treatment		
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
PS LF CE X	8.75	1.9	6.38	1.51	$F(1,11)=105.83$, $p<0.001$	10.19	0.83	8.98	0.7	$F(1,11)=66.437$, $p<0.001$
PS LF CE Y	8.15	2	5.62	1.69	$F(1,11)=182.45$, $p<0.001$	10.21	0.89	8.86	1.02	$F(1,11)=102.87$, $p<0.001$
PS LF OE X	5.94	0.61	4.41	0.58	$F(1,11)=284.63$, $p<0.001$	6.87	0.86	5.73	0.81	$F(1,11)=426.29$, $p<0.001$
PS LF OE Y	5.13	0.53	3.79	0.54	$F(1,11)=516.50$, $p<0.001$	5.7	0.55	4.62	0.5	$F(1,11)=669.55$, $p<0.001$
Surface OE	721.36	188.75	499.72	210.67	$F(1,11)=75.549$, $p=00000$	918.81	2062.83	703.12	1855.42	$F(1,11)=91.952$, $p<0.001$
Surface CE	1742.83	323.98	1154.44	214.79	$F(1,11)=160.13$, $p<0.001$	183.81	287.87	133.83	280.88	$F(1,11)=61.980$, $p<0.001$
Length OE	654.89	109.42	407.92	99.55	$F(1,11)=248.43$, $p<0.001$	768.47	1100.35	633.98	968.85	$F(1,11)=135.78$, $p<0.001$
Length CE	942.01	190.5	642.31	180.9	$F(1,11)=443.51$, $p<0.001$	105	126.58	110.16	108.4	$F(1,11)=140.61$, $p<0.001$
DHI-P	17.83	4.13	9.66	2.05	$F(1,11)=76.112$, $p<0.001$	25	2.33	17.5	2.71	$F(1,11)=225.00$, $p<0.001$
DHI-E	22.66	3.22	12.83	2.16	$F(1,11)=188.63$, $p<0.001$	25.33	3.22	18.33	2.38	$F(1,11)=323.40$, $p<0.001$
DHI-F	20.66	5.41	11	3.35	$F(1,11)=142.32$, $p<0.001$	20.5	4.44	13.66	3.49	$F(1,11)=313.41$, $p<0.001$
Total DHI	61.16	7.25	33.5	4.98	$F(1,11)=423.35$, $p<0.001$	70.83	4.7	49.5	3.63	$F(1,11)=1185.7$, $p<0.001$
DGI	12.5	1.62	19	1.47	$F(1,11)=619.67$, $p<0.001$	10.5	1.97	14.41	2.02	$F(1,11)=292.76$, $p<0.001$
ABC	64.91	5.94	72.41	6.15	$F(1,11)=322.83$, $p<0.001$	56.66	5.83	62.58	5.35	$F(1,11)=518.23$, $p<0.001$

Significant changes in main otoneurological, self-report and performance measures before and after vestibular rehabilitation protocol in unilateral vestibular hypofunction (UVH) older adults and mild cognitive impairment (MCI) patients

Exact *p* values are given in the text

PS power spectra, *LF* low-frequency interval, *OE* opened eyes, *CE* closed eyes, *X* X plane, *Y* Y plane, *VOR* vestibular–ocular reflex, *DHI* Dizziness Handicap Inventory, *P* physical, *E* emotional, *F* functional, *DGI* Dynamic Gait Index, *ABC* activities-specific balance confidence scale, *SD* standard deviation

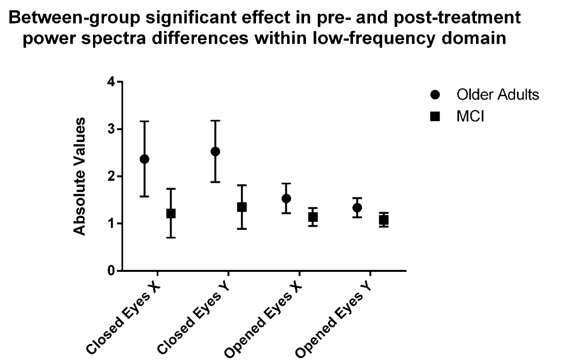

Fig. 2 Mean and standard deviations of significant pre-/post-treatment power spectra differences on X and Y planes when comparing older adults and mild cognitive impairment (MCI) unilateral vestibular hypofunction (UVH) patients

[26]. In this scenario, the link between the vestibular system—and its VR-related recovery—and cognitive domains is further supported by the findings that projections by the vestibular system—partially involved in VR networks—may occur at different stages in the processing stream [27], especially in the temporal lobe and hippocampus, involved in memory and spatial orientation [8, 28, 29]. These notions are indirectly confirmed by neuroimaging studies showing hippocampal atrophy and spatial navigation task deficits [30] in bilateral vestibular loss patients [28] and vestibular-lesioned animal models [8, 31]. On the other hand, the cortical inhibitory sensory–sensory interaction and reduced excitability of the V5/MT area [32] were found to have a potential aging-related role in information processing-balance/vestibular interference [33, 34]. By means of these notions it has been understood that descending and ascending neural influences may exist between the two systems inducing cognitive and postural changes, respectively [33].

Although a significant post-treatment effect was found in both groups (Table 3), these aspects are further corroborated by the significant lower Δ scores in PS values in the low-frequency domain, surface and length parameters in MCI patients when compared to older adults, detecting a more lenient behavior in reacting to VR in the first group (Fig. 2; Table 2). As known, body sway within these frequency intervals is considered to be mainly under vestibular control [16, 19, 35–37] and patients with vestibular deficits and compensation have consequently increased and decreased body sways, respectively [3, 38]. Previous theories posited vestibular–hippocampal connections underlying the association between vestibular loss and dementia [7, 8] and demonstrated cognitive declined patients with or without vestibular deficit as affected by increased values in body sway [7, 39] and lower mean amplitudes in sacculocollic reflex when compared with age-matched controls [40]. Thus, significant between-group Δ scores effect within the low frequency domain could point the attention to possible cognitive-related maximizing phenomena of vestibular discharge improving the vestibular source of spatial information and subsequent central reweighting and related postural control after VR protocols [8, 41].

Further evidence of these aspects resides in significantly positive correlations that were found—when combining all UVH cases—between MMSE and both surface in closed eyes condition and PS values within low-frequency interval on Y plane in closed eyes condition (Fig. 3). Considering that no differences in terms of pre-treatment VOR gain and age were found, the progressive reduction in such parameters along with the cognitive decay phenomenon may provide greater insight into those central processing rearrangement of corticospinal activity involved in VR in older adults [42] and confirms—in terms of rehabilitation outcomes—previous works highlighting the relationship between the cognitive-related deterioration and those executive functions pivotally involved in maintaining postural balance with aging [7, 43].

Finally, although a general significant change in performance measures was recorded (Table 3), DHI, DGI and ABC Δ scores were found to significantly improve in older adults when compared to MCI patients (Table 2). This aspect—together with the positive correlation found between MMSE

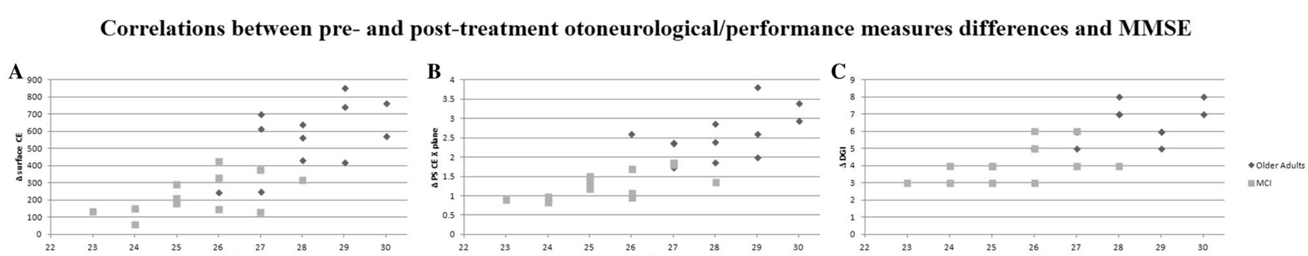

Fig. 3 Single-case plotted scatterplots of correlations **a** between pre–post treatment differences (Δ) in surface of the ellipse of confidence during closed eyes condition (CE) and Mini-Mental State Exam (MMSE) scores; **b** between low-frequency power spectra (PS) Δ values during CE on X plane and MMSE scores and **c** between Dynamic Gait Index Δ values and MMSE scores in unilateral vestibular hypofunction (UVH) older adults and mild cognitive impairment (MCI) patients

and Δ DGI—reinforces those hypothesis supporting that cognitive decline might be centrally engaged in balance control [7, 39] and—consequently—in recovering from a vestibular deficit, also in terms of daily performances and perceived disability.

In conclusion, as vestibular-related dizziness among cognitive declined patients is not only due to peripheral vestibular disorder, but also due to a central dysfunction involving the pathways from the vestibular nucleus to limbic and cortical regions involved in both cognition and orientation [44], changes related to VR may thus critically depend on such brain and cognitive impairment upon vestibular input [45]. In this scenario, present preliminary results suggest that—together with future studies—the insight of cognitive domains has to be adequately evaluated in those older adults scheduled for VR protocols. In fact, considering that cognitive decline has above demonstrated to impact on otoneurological outcomes which may finally influence disability consequences, future research protocols could be encouraged to take the present experience into account in order to cognitively screen UVH patients undergoing VR. Such a behavior could be pivotal in devising—in clinical practice—tailored VR to improve outcomes and reduce the risk of falls and to be bedridden, especially in case of large sample of patients.

In this perspective, although the methodological aspects and results of the study are in line with previous literature, it is to highlight that present pilot findings—possibly limited by small sample size of groups due to enrolment difficulty—suffer from a limitation which has to be elucidated. Some factors—such as the adherence of an adequate numbers of older patients to the study—finally affected the possibility to enroll a larger sample size of participants. We tried to overcome such possible limitation with a grouping model equally spreading in both groups socio-demographic and disorder-related variables. On the other side, the statistical approach—treating the mentioned confounding effects as predictors, including a confidence interval of 95% and applying the over-conservative post hoc correction to prevent the possibility of increasing the likelihood of type I statistical errors—has been conceived to reduce the chance of erroneously accepting the null hypothesis.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to disclose.

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