Original article (short paper)

Postural balance in Alzheimer's disease patients undergoing sensory pitfalls

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Abstract—Despite consensus regarding the interference of cognitive processes on the human balance, the impact that different sensory stimuli have on the stabilometric measures remains unclear. Here, we investigated changes in the postural balance of individuals with Alzheimer's disease (AD) and in healthy controls undergoing different proprioceptive and somesthetic pitfalls. We included 17 subjects submitted to eight sensorimotor dynamics with differences in the support bases, contact surfaces, and visual clues. The measurements used to assess participants balance were as follows: position of the body in space, range of instability, area of the support base, and velocity of postural control. From a total of 56 cross-sectional analyses, 21.42% pointed out differences between groups. Longitudinal analyses showed that tasks with proprioceptive and somesthetic pitfalls similarly impact imbalance in both groups. The current results suggest that AD subjects and healthy controls had different patterns submitted to balance, but suffered similar interference when undergoing proprioceptive and somesthetic challenges.

Keywords: postural balance; Alzheimer's disease; sensory deprivation; sensory feedback

Introduction

The age advance constitutes a real challenge to governments and health care institutions in keeping the subjects healthy and with a proper quality of life[1]. Besides the presence of several age-related changes that hinder the daily living activities, older adults have to deal with complications caused by chronic diseases, increased risk of falls, and other disabling injuries[1,2].

The World Health Organization classifies fall prevention as a public health challenge worldwide[3]. Several factors contribute to an increased risk of falls in the elderly: reduced physical activity, loss of muscle strength, fear of falling, worst visual acuity, impaired mobility, weaker proprioceptive response, and decreased agility[4,5]. However, it is the association with chronic illness, such as Alzheimer's disease (AD), that makes imbalance so common and highly disturbing in advanced aging[5,6].

AD is a chronic and neurodegenerative condition characterized by the presence of the protein beta amyloid around neurons and the accumulation of an abnormal form of the protein tau inside neurons. The hallmark of AD is a progressive cognitive dysfunction; the symptoms begin with a gradual worsening of the ability to remember new information, followed by difficulties in solving problems, confusion with time or place, problems in understanding spatial relationships, and misplacing things[7].

Studies have pointed out the importance of balance problems in patients with AD[8-11]. Explanations for such problems go beyond the complexity of the task, the more challenging the tasks are the higher seems to be the cognitive load and the risk of falls for the subject[12]. However, because human bipedal stance is achieved by a complex network formed by biofeedback mechanisms[13], neurophysiological changes experienced by AD subjects may result in alterations in the sensory integration process, impacting one's static and dynamic balance[10,14].

Imbalance is proportionally increased as the level of cognitive impairment of the subject becomes higher, and sensory integration is crucial to maintain postural control in healthy subjects[14]. However, the investigation of balance in AD subjects undergoing different proprioceptive and somesthetic clues remains scarce.

Here, we compared the balance performance in age- and gender-matched individuals without AD with the performance of older adults with AD undergoing different sensory stimuli. The hypothesis raised by the authors is that both AD and control groups would be considerably affected by situations having less sensory clues (particularly when visual clues are absent and when proprioceptive feedbacks are inaccurate), but with the highest imbalance in the AD group.

Methods

Participants

In total, 17 individuals (mean age ± standard deviation: 73.35 ± 5.70 years) recruited from the Neurologic Physical Therapy Outpatient Clinic of the Federal University of Mato Grosso do Sul were enrolled in this trial. This study was conducted as per the principles expressed in the World Medical Association Declaration of Helsinki. All participants provided written consent and the study was previously approved by the Human Research Protection Office (n. 013503/2015).

The inclusion criteria involved community-dwelling participants diagnosed with AD[15]. All participants were independent for orthostatism and locomotion and did not perform any physical activity superior to three metabolic equivalents of task (borderline limit that includes only light intensity activities), and with disease severity I to II, according to Clinical Dementia Rating[16]. Healthy controls were included such that their results would be compared with those of AD subjects; their selection matched the socio-demographic characteristics criteria of the AD group.

The exclusion criteria involved participants with neurological conditions different from AD, those with any non-physiological conditions that could potentially impact balance (such as musculoskeletal disorders, amaurosis, agnosia of any kind, and vestibulopathy), with a history or in use of psychotropic or antipsychotic drug, and those who could not attend (for any reason) the outpatient clinic. Furthermore, none of the participants had been hospitalized in the previous 6 months.

Methodological procedures

All methodological procedures (general setting, participants, variables, data measurement, and statistical methods) were supported by the STROBE Statement checklist.[17] The assessments of this study involved one main outcome (stabilometry measures) and eight predictors, impacted by different proprioceptive and somesthetic clues.

The stabilometric measures were assessed by means of a calibrated BIOMEC 400_V4 force platform (EMG System®) consisting of a 500 mm^2 plate, four load cells, and a calibration system of 100 Hz. Balance tests were conducted at the research laboratory as part of a set of examinations of health and functional abilities. Each participant performed the balance tests during afternoon hours. A 30-min rest interval preceded all tests.

The assessments involved eight different tasks, in a way to measure balance in different support bases, visual clues, and contact surfaces. During the balance evaluation, the subjects were asked to stand still on the platform under the following conditions:

1. feet in parallel with a support base of 30 cm, no foam, and eyes open (SB30-EO);
2. feet in parallel with a support base of 30 cm, no foam, and eyes closed (SB30-EC);
3. feet in parallel with a support base of 10 cm, no foam, and eyes open (SB10-EO);
4. feet in parallel with a support base of 10 cm, no foam, and eyes closed (SB10-EC);
5. feet in parallel with a support base of 30 cm on a 6 cm-thick foam (density of 57 g/dm^3) placed on top of the force plate, with eyes open (FOAM-EO);
6. feet in parallel with a support base of 30 cm on a 6 cm-thick foam (density of 57 g/dm^3) placed on top of the force plate, with eyes closed (FOAM-EC);
7. semi-tandem position (dominant leg ahead of the other as if taking a step), no foam, and eyes open (ST-EO);
8. semi-tandem position (dominant leg ahead of the other as if taking a step), no foam, and eyes closed (ST-EC).

The delimitation of eight different tasks was set due to the intention of assessing balance during several sensory pitfalls. Therefore, while SB30-EO represents the condition in which the subjects had a more sensory feedback (with stimuli provided by the visual, proprioceptive, and somatosensory systems), FOAM-EC and ST-EC represent conditions that provided more inaccurate clues (with eyes closed on foam or on semi-tandem position). Thus, with this setup, we could analyze balance in situations where the proprioceptive, visual, and somesthetic systems were less and more disturbed.

The tasks order was randomized for each participant. The subjects performed all the tests barefoot. The measurements used to assess the participants balance were as follows: position of the body in space (cm), range of instability (cm), area of the support base (cm^2), and velocity of postural control (cm/s). While it is common to use the center of pressure to assess one's balance, in this study, we added more predictors to the analyses in order to obtain a complete view of the postural control of the subject. The included variables involved both the anterior-posterior and the mediolateral axes.

For safety precautions, participants' arms could be used for balance correction only in the imminent risk of fall. Two researchers stood by each side of the subject during the assessments and, in case of imminent risk of fall, the subject was allowed to stop the activity and do it later.

The Mini-Mental State Examination[18] (MMSE), the Frontal Assessment Battery (FAB)[19], and the Montreal Cognitive Assessment (MoCA)[20] were applied to all participants to assess general measures of cognitive and executive functioning. The Clinical Dementia Rating (CDR)[16] was used to evaluate the disease severity of the Alzheimer's group. These instruments were applied only at the beginning of the study for characterizing the groups.

Statistical analysis

The data analyses involved descriptive and inferential statistics. As the parametric precepts were not contemplated in all variables, we standardized the use of non-parametric statistics.

The groups were characterized by median, as a central tendency measure, and interquartile range, as a variability measure. The between-group analyses were assessed with two tests: the qui-square test to compare the proportion of subjects and sex

distribution in each group and the Mann–Whitney U test to compare groups as per cognition and balance tasks. To investigate how the different support bases, contact surface, and visual clues affected the balance of each group, we performed longitudinal analyses with Friedman's test associated with contrast analyses. The level of significance was set at 5% ($p < 0.05$).

Results

In total, 17 participants were divided into two groups: AD (n = 8) and control (n = 9). Table 1 shows that the data from both groups are statistically similar in terms of sample size, sex, age, and educational level. In contrast, groups are different concerning general aspects of cognition and executive function. Participants with AD were all in the mild and moderate stages of the disease, as reflected by CDR scores.

Table 1. Group characterization of the participants.

Variables	Alzheimer group	Control group	p
Sample size	8	9	.808
Sex (male:female)	2:6	2:7	.893
Age (years)	74.50±10.00	71.00±8.00	.209
Schooling (years)	3.50±3.50	4.55±3.32	.682
CDR (points)	1.50±1.00	-----	-----
MMSE (points)	12.50±12.50	28.00±3.00	.001
FAB (points)	8.00±11.50	17.00±4.00	.011
MoCa (points)	9.00±15.50	26.00±10.00	.004

CDR: Clinical Dementia Rating. MMSE: Mini-mental State Examination. FAB: Frontal Assessment Battery. MoCa: Montreal Cognitive Assessment. Data are expressed in median ± interquartile range.

Stabilometry

The values of the subject's balance submitted to different support bases, contact surfaces, and visual clues are presented in Table 2. From the 56 cross-sectional analyzes involving the comparisons of AD participants and controls, only 12 (21.42%) demonstrated the differences between groups. The differences were found in the mediolateral position (FOAM-EO, FOAM-EC, and ST-EO), anterior–posterior velocity (SB30-EO, SB10-EO, FOAM-EO, and FOAM-EC), and mediolateral velocity (SB30-EO, SB30-EC, SB10-EO, FOAM-EO, and FOAM-EC).

Descriptive analyses of the data indicated that, unlike our original hypothesis in which AD patients would present worst balance than controls, the findings pointed to a different way. The control subjects demonstrated a higher mediolateral deviation and velocity of dislocation for both anterior–posterior and mediolateral axes, reflecting a higher imbalance and risk of falls.

Paired analyses revealed significant variations of balance in AD subjects when comparing the stabilometric variables under the eight evaluated situations ($p < 0.05$ for all variables). The contrast analyses confirmed the great instability on balance when the support bases are small and visual clues are absent. In the control group, the subjects demonstrated variation of stabilometric variables on all tasks investigated ($p < 0.05$ for all comparisons), with the exception of the mediolateral position ($p = 0.199$). The contrast analyses confirmed a similar variables result because it was in the AD group (Table 3).

Table 2. Median ± interquartile range of balance values during different tasks.

Tasks	Groups	AP position (cm)	ML position (cm)	AP range (cm)	ML range (cm)	Area (cm²)	AP velocity (cm/s)	ML velocity (cm/s)
SB30-EO	Alzheimer	-0.32±1.68	-0.20±1.94	1.21±3.22	0.49±1.86	0.87±3.90	0.84±0.78	0.76±0.39
	Control	-2.78±6.64	-1.00±2.01	2.17±0.74	1.29±0.77	1.46±1.09	1.31±0.24	1.05±0.27
	p(Alz x Ctl)	.123	.501	.563	.386	.630	**.027**	**.043**
SB30-EC	Alzheimer	-0.31±1.76	-0.08±2.23	0.88±3.21	0.46±1.38	0.55±2.12	1.00±0.87	0.76±0.45
	Control	-1.93±4.67	-0.67±2.27	2.54±1.22	1.17±0.37	1.36±1.28	1.38±0.68	1.05±0.37
	p(Alz x Ctl)	.067	.248	.149	.413	.335	.123	**.027**
SB10-EO	Alzheimer	-0.26±0.34	0.34±1.16	1.20±2.88	1.66±3.52	1.89±7.13	0.91±0.90	0.94±1.20
	Control	-1.19±4.39	-0.76±0.74	3.46±1.77	3.27±0.67	5.37±3.72	1.45±0.48	1.65±0.51
	p(Alz x Ctl)	.211	.228	.060	.149	.247	**.012**	**.024**
SB10-EC	Alzheimer	-0.25±0.72	0.27±1.52	1.70±4.55	2.19±5.58	3.99±15.01	1.03±1.66	1.11±1.82
	Control	-0.45±3.41	-0.87±0.89	3.72±1.57	3.76±0.84	6.56±4.57	1.73±0.94	2.10±0.93
	p(Alz x Ctl)	.149	.290	.336	.923	.563	.149	.149
FOAM-EO	Alzheimer	-0.27±1.19	0.36±0.64	1.53±3.84	0.99±3.04	2.09±4.59	1.00±1.34	0.78±0.67
	Control	-2.73±3.32	-1.05±1.00	3.21±1.44	2.15±1.36	3.39±4.70	1.81±0.68	1.34±0.68
	p(Alz x Ctl)	.149	**.009**	.290	.336	.247	**.038**	**.016**
FOAM-EC	Alzheimer	-0.51±1.51	-0.46±1.38	1.91±4.60	1.01±2.09	1.83±6.88	1.05±1.64	0.79±0.53
	Control	-2.77±3.66	-1.43±1.35	3.23±0.85	2.30±1.55	3.30±2.68	2.23±0.98	1.24±0.71
	p(Alz x Ctl)	.149	**.027**	.501	.083	.500	**.027**	**.016**
ST-EO	Alzheimer	-0.26±4.41	0.36±3.84	1.33±2.97	1.40±4.12	2.16±5.89	0.96±1.23	0.89±1.34
	Control	-4.11±2.20	-1.24±1.74	2.32±0.75	2.50±1.54	2.52±1.98	1.50±0.77	1.43±0.52
	Sig(Alz x Ctl)	.149	**.021**	.386	.630	.700	.178	.178
ST-EC	Alzheimer	-0.27±2.72	0.36±1.01	1.54±2.88	1.68±5.87	2.10±9.07	1.01±1.69	0.93±1.88
	Control	-3.99±3.59	-0.50±1.96	2.34±1.39	2.80±1.84	2.59±2.70	1.76±0.82	1.54±0.50
	p(Alz x Ctl)	.083	.054	.248	.773	.847	.336	.290
All	p(Alz)	**.003**	**.045**	**.001**	**.001**	**.001**	**.001**	**.001**
	p(Ctl)	**.025**	.199	**.001**	**.001**	**.001**	**0.001**	**.001**

SB30-EO: support base of 30 cm, eyes open. SB30-EC: support base of 30 cm, eyes closed. SB10-EO: support base of 10 cm, eyes open. SB10-EC: support base of 10 cm, eyes closed. FOAM-EO: foam, eyes open. FOAM-EC: foam, eyes closed. ST-EO: semi-tandem, eyes open. ST-EO: semi-tandem, eyes closed. AP: Anterior-posterior. ML: Mediolateral. Significant differences are highlighted in bold numbers.

Table 3. Contrast upon the paired group analyses.

Stabilometry	Alzheimer group	$p_{Alzeimer}$	Control group	$p_{control}$
AP position	Cubic	.012	Cubic	.002
ML position	Quadratic	.082	Quadratic	.084
AP range	Linear	.005	Linear	.044
ML range	Linear	.007	Linear	.026
Area	Linear	.022	Quadratic	.008
AP velocity	Linear	.001	Linear	.003
ML velocity	Linear	.006	Linear	.029

AP: Anterior-posterior. ML: Mediolateral.

Discussion

Balance impairments have been widely described in AD patients[8-11]. Increasing cognitive and executive dysfunctions are highly associated with difficulties in maintaining an adequate body control[21]. However, because balance is a result of complex integration and coordination of several underlying systems (covering sensory, cognitive, and motor processes), we recognized the need of further studies to address the balance control in AD patients undergoing different sensory tasks.

Here, we induced the participants in several sensory pitfalls to investigate the balance response during each condition. The results partially corroborated our original hypothesis. Both groups presented greater balance instability during greater perturbation of the sensory systems (as estimated); although we expected that the AD group would have a higher imbalance than the control group. However, only 12 of the 56 cross-sectional analyses pointed out differences between the AD and control groups, with the worst performance by the control group on several tasks. This finding contradicts our initial hypothesis and can be explained by two points. First, it is possible that the data was negatively influenced by the small sample size. Second, the profile of the AD patients, selected at a Physical Therapy Outpatient Clinic, could be indicative of the fact that the patients had their balance positively affected by the physical therapy treatment.

We understand that one may argue that the sample size of our study could affect the reliability of the data, because the number of AD subjects was really low. However, the difficulty in recruiting subjects, as well as the fact that AD has a complex diagnosis, requiring the integration of clinical evaluation with neuroimaging exams (such as hippocampal volumetry and magnetic resonance spectroscopy) that are not always available has to be considered. In addition, as stated by Snowden[22], the diagnosis of AD is clinically complex, while memory impairment is the most frequent symptom of the disease, some patients may present disorders of language, perception of spatial skills, and praxis, confounding physicians. Therefore, we opted to include only subjects that presented a "pure" diagnosis of AD in order to avoid the inclusion of other dementias. Although such rigor limited our sample size, it strengthened our study in a way that provided assurance that the data were unaffected by false positive cases.

Regarding the treatments applied for AD subjects, we recognize that the participants should ideally have had activities similar to the control group (to avoid its impact on the outcome of the study). However, we must consider the ethical lapse that would have been caused if we had withdrawn the patients from their treatment. To control the interference of everyday tasks on the balance, we included only subjects that performed activities of up to three metabolic equivalents of task[23]. However, we recognize that there must have been some interference of the physical therapy treatment on the results.

Although we identified bias caused by the small sample size and the benefits of the treatment on the results, the potentials of the results must be highlighted. First, the possible impact caused by physical therapy upon balance represents great news for patients, caregivers, and health care professionals, because such treatments can be prescribed to AD patients. Second, most of the differences observed between the groups involved the velocity of correction of postural control (representing 9 of the 12 significant cross-sectional analyses). Such a variable was highlighted among the stabilometric measures, which may indicate a path to treat balance problems in neurodegenerative conditions. Finally, because both groups had similar contrast patterns (statistic used to evaluate the impact that different sensory pitfalls had in each group), the theory reporting alterations in the sensory integration process in AD is not endorsed. Thus, when a stable stance was perturbed in AD and control subjects, sensory signals processed by the central nervous system seems to act equally, trying to promote adequate postural control in both groups.

Previous studies have pointed out a similarity in the motor behavior of AD and control individuals. Besides the close values between groups, indirect measures, such as high variability of values, may indicate that the tasks are more difficult for AD subjects than the general population, even in the absence of group differences[24,25].

Nevertheless, given that both groups presented a similar pattern of contrast, reporting an adequate response of the sensory integration process, how can we justify well-grounded studies found impacting balance problems in AD? The low scores found in this study for general cognition and executive function indicate that such factors may play a key role in controlling balance. This hypothesis corroborates previous publications that pointed cognition as the main issue affecting motor function in older adults[21,26-28].

Limitations

Although the current study provided important information about the postural balance of AD individuals, it has some limitations that need to be considered. We recognize that potential effects caused by the small sample size and by physical therapy could have affected the results. Furthermore, only participants with mild to moderate degrees of compromise resulted from AD were enrolled in this study. Subjects with severe compromise were excluded because independence for orthostatism and locomotion is unusual in advanced stages, and a severe cognitive compromise could make the understanding of the tasks difficult for the patient.

Conclusion

AD subjects have different pattern of postural control when compared with healthy participants. Our results do

not support the hypothesis that changes caused by AD result in alterations in the sensory integration process. Although this was not an objective of the study, the results suggest a positive influence promoted by physical therapy upon the balance of AD subjects.

An important strength of this study is the confrontation of balance during difference sensory stimuli in subjects with cognitive impairment. Considering that one of the health care professionals' goals is to improve patients' quality of life, our results may support those professionals in planning new interventions for people with AD. Furthermore, we believe that the findings of this research can bring new discussions about how to provide proper stimulation for the patient during every day sensorial challenges.

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