Cerebral Activation Patterns Of Older Adults While Performing The Functional Gait Test

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Abstract

Dual-task activities are common in daily life and have greater motor/cognitive demands. These are conditions that increase the risk of older adult falls. Falls are a public health problem. Brain mapping during dual-task activities can inform which therapeutic activities stimulate specific brain areas, improving functionality, and decreasing dependence and the risk of falls. The objective of the study was to characterize the brain activity of healthy older adults while performing a dual-task activity called the Functional Gait Test (FGT). Method : This observational study included 30 older adults aged 65 to 75 years, and it was approved by the institutional review board. The FGT consists of walking following a sequence of numbers (simple task), and a sequence of alternating letters and numbers (complex task). During the activity, the subjects had their cortical activation pattern measured using the Emotiv EPOC® electroencephalogram. Complete data was obtained for analysis on 13 participants. The data was analyzed using descriptive statistics (mean and standard deviation), and paired T-tests to compare the brain activity during the conditions (simple vs. complex task). Results : Alpha brain waves were activated in the right and left hemispheres during the simple task, while Alpha brain waves' activation during the complex task was predominant in the right hemisphere. However, the differences were not statistically significant. The Betha waves had predominant activation in the left hemisphere during the simple task, and predominant activation in the right hemisphere during the complex task. The difference was statistically significant in 11 out of the 14 channels evaluated ($P<0.04$). Conclusion: The results corroborates the increased complexity of dual-tasks due to the predominant activation of the right hemisphere, which is related to motor learning process and new stimulus processing.

Background

The older adult population is increasing worldwide [1]. Aging is associated with morphological, functional and biochemical changes that affect the organism and make older adults more susceptible to physical, motor and cognitive disorders such as decrease range of motion, cognitive impartment and dementia, deficits in strength and balance. These changes lead to functional impairments and increased dependence. Aging-related balance impairment is related to inadequate functioning of the vestibular, visual, somatosensory and musculoskeletal systems, and increase the risk of falls [2-5].

Falls in older adults are a public health problem; 30 to 40% of the community dwelling older adults fall at least once a year. Falls are the number one cause of injuries and injury-related deaths among older adults [6-8]. Poor performance in dual-task (DT) activities is associated with a higher risk of falls in older adults. DT activities are characterized by performing a main and a secondary task simultaneously. There is a decline in the performance of DT with advancing age, which can make older adults more dependent because many activities of daily living (ADLs) involve DT such as walking and talking, and crossing streets [9-12]. Knowing brain activation behavior during the performance of a DT is important for understanding the processing of new stimuli, to target specific therapeutic approaches. To execute motor tasks, activation and communication of the neuronal impulses of cortical areas responsible for the specificities of each task are necessary. The brain activation behavior during execution is still a matter of investigation.

Electroencephalography using non-invasive and wireless interfaces is used to monitor brain activity during the performance of motor tasks. The electroencephalogram (EEG) is the electrical signal generated by a group of neurons underlying the electrodes of the respective interface. The frequency generated by the EEG characterizes brain waves into delta (0.5-4Hz), theta (4-8Hz), alpha (8-13Hz), beta (13-30Hz) and gamma (above 30Hz). In addition to presenting a specific characteristic with regard to frequency, each wave is more evident in particular situations. Alpha waves are usually associated with waking and being in a relaxed condition, being minimized in conditions that require attention or mental effort. Beta waves are evidenced in alert or focused attention situations and tasks that demand more cognitive effort and can be present in several cortical regions, but are more evident in the motor function areas [17]. Brain mapping in older adults during DT can direct clinical practice to activities that stimulate specific cortical areas in order to improve the execution and learning of specific motor tasks, improving functionality and independence [18, 19].

The Trail Making Test (TMT) evaluates divided attention during DT [13]; it is a pencil-and-paper test that provides information on search ability by visual scanning processing speed, cognitive flexibility, divided attention, motor agility, ability to switch tasks motor inhibition and coordination [14-16]. Voos (2009) created a test with the same characteristics, but with a greater motor demand and called it the Functional Gait Test (FGT) [16]. It consists of two stages; in step A the subject must walk on a carpet following a numbered sequence (simple task), and in step B the subject must do the same but following a sequence of alternating numbers and letters (complex task). Despite the availability and large adoption of the FGT, and of the capability of recording EEG non-invasively, little is known about the patterns of older adults' brain activation during the FGT. Investigating the EEG and mapping the brain waves in older adults while performing a DT activity is important to inform rehabilitation. The objective of the present study was to characterize the brain activity behavior of healthy older adults while performing the FGT.

Materials And Methods

Participants

An observational study was carried out at a public hospital in (city), (state), (country). The project was approved by the institutional review board. The participants were 30 older adults of both genders recruited from the community and from the geriatrics and physiotherapy clinic of the hospital. The inclusion criteria were age between 65 and 75 years, Short Physical Performance Battery (SPPB) score > 7, Mini Mental State Examination (MMSE) score > 24 for the older adults with more than one year of education and > 19 for those with no school education, no use of assistive devices for walking, hemodynamically stable, no history of photic epilepsy, and no vestibular disorders. The exclusion criteria were to have participated in DT activity studies in the prior to 6 months, nausea and/or balance impairment.

Given the technical difficulties of the existing technology, 17 participants had data with a lot of noise even after filtering (high noise/signal ratio). The data from these participants were not included in the analysis. Therefore, data was analyzed for the 13 participants who had data with a small noise/signal ratio. The 13 subjects included in the analysis were 71 ± 3 years old, had 7 ± 5 years of education, SPPB scores of 10 ± 1, MMSE scores of 26 ± 4.

Instruments and procedures

After voluntary agreement to participate, the individuals signed an informed consent form according to resolution 466/12 of the National Health Council. Then, the participants completed an evaluation form, the MMSE and the SPPB. After that, the participants were instrumented with the Emotiv EPOC® EEG equipment. It was positioned following the guidance provided by the manufacturer. The 14 electrodes were hydrated with saline solution to facilitate conduction and registration of the electrical signal through the scalp. After hydration, the device was positioned so that each electrode was in close contact with the analyzed region under the scalp. Two reference points were positioned bilaterally in the temporal region immediately above the ears, and the AF3 and AF4 electrodes were positioned 4 cm above the eyebrow. After setup, the equipment was activated, and signal quality was checked.

After instrumentation, the participants completed the FGT on a black mat. In part A (simple task), there are 25 black numbers (1 to 25) displayed in light gray circles distributed along the mat, and in part B (complex task) there are 13 black numbers (from 1 to 13) and 11 black letters (A to M, without the letter K) displayed in light gray circles on a black mat of the same size. In part A, the subject was instructed to follow the sequence of numbers until reaching the last number; and in part B, the subject was instructed to follow the sequence of alternating numbers and letters until they reach the last number or letter on the mat. The evaluator timed the test; if/when the subject made a mistake on the sequence, he/she was instructed to return to the previous number or letter and then continue without stopping the timer. The evaluator encouraged the subjects to perform the test in the shortest time possible. After completion, the time and the number of mistakes in each part were recorded and the EEG equipment was removed. The assessment lasted approximately 1 hour per participant.

Data analysis

The power of the alpha (8–12 Hz) and beta (13–30 Hz) waves during the middle twenty-second windows of the simple and complex tasks were analyzed. The data was filtered to remove noise (EEG signals > 100 mV) [20]. After filtering, the largest signal common to all channels and subjects was found (lowest noise/signal ratio). Signal normalization for the power analysis was performed based on Zscores - number of standard deviations from the mean for each data point. Nine wave frequencies were generated for the alpha waves (8–12 Hz at 0.5 increments), and 35 wave frequencies were generated for the beta waves (13–30 Hz at 0.5 increments). The mean and standard deviation values were calculated for each frequency and channel. EEG activation maps were created at 10 and 17 Hz for the alpha and beta waves respectively.

Statistical analysis

The descriptive analysis was performed, the Shapiro Wilk test was used to test the data normality, and paired T-tests were used for comparing the means of the simple and complex tasks.

Results

The participants took 128±96 seconds to complete the simple task and 284±138 seconds to complete the complex task (*P*=0.025), and the tasks were completed with 1±2 and 2.4±2 errors respectively (*P*=0.004).

Figures 1A and 1B show the mapping of alpha waves during the performance of the simple and complex tasks respectively. There was approximately symmetrical activation in the right and left hemispheres in part A (simple task), while a predominance of activation in the frontal area and right hemisphere in part B (complex task).

In Figures 2A and 2B, the beta wave behavior was observed while performing parts A and B of the DT activity. Greater activation was found in the left hemisphere in part A (simple task), while a predominance of activation in the right hemisphere in part B (complex task).

Table 1 presents the comparative analysis of the alpha wave, in performing parts A and B of the DT for the 14 EEG channels. The results indicated that there was no significant difference in any of the 14 channels evaluated.

Table 1 - Comparative analysis of the alpha wave power (Zscores) between parts A and B in the 14 EEG channels.

Channels	**PART A**		**PART B**		***P-value***
	Mean	SD	Mean	SD	
AF3(1)	0.034	0.029	0.036	0.030	0.70
AF4(2)	0.034	0.027	0.035	0.029	0.46
F3 (3)	0.029	0.027	0.030	0.026	0.77
F4 (4)	0.036	0.029	0.036	0.032	0.97
F7 (5)	0.036	0.029	0.033	0.027	0.38
F8 (6)	0.036	0.031	0.034	0.029	0.70
FC5(7)	0.036	0.029	0.034	0.032	0.31
FC6(8)	0.034	0.027	0.034	0.029	0.80
T7(13)	0.034	0.031	0.038	0.032	0.65
T8(14)	0.035	0.029	0.035	0.030	0.70
P7(11)	0.038	0.032	0.036	0.032	0.75
P8(12)	0.033	0.028	0.038	0.033	0.22
O1(9)	0.036	0.029	0.036	0.030	0.65
O2(10)	0.037	0.036	0.044	0.037	0.42

Table 2, presents the comparative analysis of the beta waves, in performing parts A and B of the DT for the 14 EEG channels. It was observed that only 03 channels (10, 11 and 14) did not present significant differences.

Table 2 - Comparative analysis of the beta wave power (Zscores) between parts A and B in the 14 EEG channels.

Channels	**PART A**		**PART B**		***Pvalue***
	Mean	SD	Mean	SD	
AF3(1)	0.027	0.023	0.032	0.037	0.01*
AF4(2)	0.025	0.022	0.037	0.033	0.01*
F3 (3)	0.026	0.024	0.047	0.040	0.01*
F4 (4)	0.028	0.023	0.038	0.034	0.01*
F7 (5)	0.027	0.023	0.039	0.033	0.01*
F8 (6)	0.029	0.023	0.039	0.034	0.03*
FC5(7)	0.029	0.024	0.039	0.035	0.01*
FC6(8)	0.026	0.022	0.038	0.031	0.03*
O1(9)	0.032	0.026	0.037	0.032	0.01*
O2(10)	0.036	0.028	0.035	0.025	0.75
P7(11)	0.032	0.025	0.038	0.029	0.22
P8(12)	0.033	0.025	0.039	0.038	0.01*
T7(13)	0.028	0.024	0.039	0.033	0.03*
T8(14)	0.027	0.027	0.037	0.029	0.46

Discussion

The participants did not have cognitive impairments and had moderate physical fitness. Still, the participants took more than double the time to complete the complex task compared to the simple task, with more than twice the number of errors.

Balance and gait control, especially during dual tasks, occurs in brain centers that are activated during tasks with high cognitive processing demand (i.e. in regions related to executive functions). When activities are performed simultaneously, the performance in one or both activities can be adversely affected [21–22].

Little & Woollacott (2014) [23] compared the evoked potential/N1 response (balance sensory processing) during a simple and a dual task (cognitive + balance) using EEG, and found attenuation of N1 activity during the dual task. This indicates that competition for attentional resources was associated with performance impairment in both cognitive and balance aspects. These findings help to explain the longer execution time and greater number of errors we found in our study during the complex dual task.

Johannsen et al. (2013) [24] reported that under conditions of attentional competition in dual task situations, compensatory strategies prioritize the maintenance of gait with greater impairment of cognitive performance. In our study, there was a greater activation of alpha waves in the prefrontal cortex during the greater complexity dual task. The prefrontal cortex is an area of strong activation in dual task conditions because it is related to executive functions [25]. The higher the complexity of a task, the greater the activation of the pre-frontal cortex of older adults and individuals with gait dysfunction [26–29]. Wagshul et al. (2019) [30] investigated the activation of the prefrontal cortex of older adults during single and dual-task gait using different neuroimaging techniques and found that the greater the cognitive complexity of the task, the greater the activation of the prefrontal area. This corroboratees our finding and those of other studies [31–32].

The beta-wave cerebral mapping showed that there was increased activation of the left prefrontal area (working memory) during the less complex task. This finding corroborates those of several previous studies of activities by older adults [33–35]. During the greater complexity dual task, the greater activation of beta waves was in the right temporal lobe. These area is related to learning, memory, spatial processing and auditory, tactile and visual integration [36].Temporal cortex also contributes to the processing of verbal and non-verbal information, being is of great importance for working memory in conjunction with the prefrontal cortex [37]. Schon, et al. (2013) [38] compared the activation of the temporal and frontal cortex using functional magnetic resonance imaging (FMRI) during familiar and unfamiliar tasks, and found that the temporal cortex is activated with the frontal cortex only in new working memory tasks.

In our study, there was no significant difference on the alpha waves' activation during tasks of lower and higher complexity. Alpha wave activity is observed during conditions requiring low neural effort [39–42]. Alpha activity is less in older than in younger people, especially in conditions of high cognitive demand due to the greater difficulty (greater neural effort) that the older adults have in selecting the information for appropriate response to the imputs because of aging-related impairments of the pre-frontal area functioning [43–44]. Sander, Bergner and Lindenberger (2012) [45] evaluated alpha wave activity during cognitive testing to investigate the responsiveness of working memory and found lower alpha activation in older adults compared to children and young people with increasing cognitive demands. Thus, in addition to having lower alpha wave activation, older adults alpha waves activation is less responsive to increased cognitive demands. These results corroborate the findings of the present study because we also did not find alpha wave differences between the simple and complex dual tasks.

Beta waves are related to increased motor demand and therefore are more active during activities that require greater concentration and neural effort [46–48]. This was also found in our study because there was significantly higher beta wave activity during the more complex dual task in almost all channels indicating a greater neural effort. Veldhuizen, Jonkman and Poortvliet (1993) [49] found that the older women tended to have higher beta wave potentials than younger women, even at rest. Toledo et al. (2016) [50] compared the brain behavior of younger and older adults during an ankle proprioception test using EEG and found that higher proprioceptive demands (motor sensory stimuli) were associated with increased beta wave activation in the older adults to compensate for aging-related sensory and neuromotor activity deficits. Similarly, Hübner, Godde and Voelcker-Rehage (2018) [51] investigated older adults' fine motor responses to visual stimulus, and found greater beta activation with greater test complexity.

Another relevant finding of our study was that the left hemisphere was predominanty activated in the less complex task, while the right hemisphere was predominanty activated in the more complex task. According to Goldber's theory (2002) [52], motor learning occurs from the right hemisphere to the left one, and the right hemisphere is responsible for processing new stimuli, while the left works with assimilated information. Although the more complex task was completed after the simpler task, which could favor its execution by learning and neural adaptation, greater right hemisphere activation was observed in the complex task. This fact may be explained by the greater cognitive demand imposed by the complex task which required following an alternating sequence of letters and numbers, resulting in longer time for completion and grater number of errors. A review by Luft and Andrade (2006) [53] emphasized that Goldberg's theory is complemented by the idea that learning follows a specific process for each skill, where structures that are not directly involved with the specific activity cease to be activated saving energy to be directed to the areas of task execution [54]. This expanded theory corroborates the finding that specifics areas were activated in executing the more complex task. Other studies also found the right hemisphere to be more activated in activities with greater complexity than the left hemisphere; this difference in activation is usually identified when comparing different regions and not the right and left hemispheres as a whole [55–57].

Limitations of the study include the lack of single tasks because the conditions compared were a simple and a complex dual task. The inclusion of a single task could provide additional information and serve as a control condition. The evaluation of the subjects in a baseline condition could clarify the possibility of lower alpha wave responsiveness to increased complexity in older adults. Another limitation was the use of low density EEG with high noise probability what resulted in the need to exclude many participants.

Conclusions

The greater complexity of part "B" of the Functional Gait Test was confirmed by the longer performance time, greater number of errors, greater activation of the beta waves, and by the predominant activation of the right hemisphere which is related to motor learning process and new stimulus processing. Strong activation of alpha-waves in the prefrontal area supported that complex dual-task activities exercise executive memory in healthy older adults.

List Of Abbreviations

ADLs: Activities of daily living

DT: Dual task

EEG: Electroencephalogram

FGT: Functional Gait Test

FMRI: Functional magnetic resonance

MMSE: Mini Mental State Examination

SPPB: Short Physical Performance Battery

TMT: Trail Making Test

Declarations

Ethical approval and Consent to participate

We hereby declare for the purposes that the present study has ethical consent approved on February 24, 2017 at the Committee of Ethics and Research with Humans of the University Hospital Onofre Lopes (HUOL), Federal University of Rio Grande do Norte (UFRN), on the basis of opinion 1,946,317 , as shown below.

Consent for publication

We declare for the purposes that this study has consent for publication by all authors involved, as shown below.

Availability of supporting date

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

Not applicable.

Funding

Not applicable.

Authors' Contributions

- LBT: ShHYPERLINK "https://dictionary.cambridge.org/pt/dicionario/ingles-portugues/he"eperformed aHYPERLINK "https://dictionary.cambridge.org/pt/dicionario/ingles-portugues/critical"critical reading of theHYPERLINK "https://dictionary.cambridge.org/pt/dicionario/ingles-portugues/same"same and is responsible for the submission of the publication;
- IFS: Acted indata collection with research participants, data tabulation and statistical analysis;
- BFLF: Acted incritical review, writing procedures, choice of manuscript and submission;
- KMY: Acted inthe analysis of the signs evidenced in the article, as well as in the use of all the essential machinery for this production;
- JMG:Acted inthe recruitment and directing of the participants, is responsible for the laboratory where the research took place and conducted the critical review;
- ERV:Acted inthe interpretation and analysisHYPERLINK "https://dictionary.cambridge.org/pt/dicionario/ingles-portugues/of"of the data, in the contextualization of the manuscript at international level and carried out a critical review of it;
- FACC: Isthe research advisor, acted in the elaboration of the project and sent to the Research Ethics Committee, followed the progress of the project and carried out a critical review.

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References

1 - Instituto Brasileiro de Geografia e Estatística [www.ibge.gov.br]. Estudos e Pesquisas: Informação Demográfica e Socioeconômica, 38. 2018.

2 - Berger H. Über das Elektrenkephalogramm des Menschen. Eur. Arch. Psychiatry Clin. Neurosci. 1935;103,1:444-454.

3 - Saalmann YB, Pinsk MA, Wang L, Li X, Kastner S. The Pulvinar Regulates Information Transmission Between Cortical Areas Based on Attention Demands. Sci. 2012;337,6095:753–756.

4 - Haegens S, Cousijn H, Wallis G, Harrison PJ, Nobre AC. Inter- and intra-individual variability in alpha peak frequency. Neuroimage. 2014;92:46–55.

5 - Samaha J, Postle BR. The Speed of Alpha-Band Oscillations Predicts the Temporal Resolution of Visual Perception. Curr. Biol. 2015;25,22:2985–2990.

6 - Jensen O. Oscillations in the Alpha Band (9-12 Hz) Increase with Memory Load during Retention in a Short-term Memory Task. Cereb. Cortex. 2002;12,8:877–882.

7 - Busch NA, Dubois J, VanRullen R. The Phase of Ongoing EEG Oscillations Predicts Visual Perception. J. Neurosci. 2009;29,24:7869–7876.

8 - Jensen O, Mazaheri A. Shaping functional architecture by oscillatory alpha activity: gating by inhibition. Front. Hum. Neurosci. 2010;4:186.

9 - O'she S, Morris ME, Iansek R. Dual task interference during gait in people with Parkinson disease: effects of motor versus cognitive secondary tasks. Phys. Ther. 2002;82(9):888-97.

10 - Yang L, Liao LR, Lam FMH, He CQ, Pang MYC. Psychometric properties of dual-task balance assessments for older adults: systematic review. J. Maturitas. 2015;80(4):359-69.

11 - Laessoe U, Hoeck HC, Simonsen O, Voigt M. Residual attentional capacity amongst young and elderly during dual and triple task walking Fisioter Pesqui. 2017;24(2):149-156 156. (11) J Hum Mov Sci. 2008;27(3):496-512.

12 - Vieira ER, Lim HH, Brunt D, Hallal CZ, Kinsey L, Errington L, Gonçalves M. Temporo-spatial gait parameters during street crossing conditions: a comparison between younger and older adults. Gait Posture. 2015;41,2:510-515.

13 - Partington J, Leiter R. Partington's Pathway Test. Psychol. Service Center J. 1949:11-20.

14 - Tombaugh TN. Trail Making Test A and B: normative data stratified by age and education. Arch. Clin. Neuropsych. 2004;19,2:203-214.

15 - Shibuya-Tayoshi S, Sumitani S, Kikuchi K, Tanaka T, Tayoshi S, Ueno S, Ohmori T. Activation of the prefrontal cortex during the Trail-Making Test detected with multichannel near-infrared spectroscopy. Psychiatry Clin. Neurosci. 2007;61,6:616-21.

16 - Voos MC. A influência da idade e da escolaridade na execução e no aprendizado de uma tarefa cognitivo-motora. São Paulo. Tese [Doutorado em Neurociências e Comportamento] - Instituto de Psicologia, Universidade de São Paulo, São Paulo, 2010.

17 - Aspinall P, Mavros P, Coyne R, Roe J. The urban brain: analysing outdoor physical activity with mobile EEGBr. J Sports Med. 2015;49,4:272-6.

18 - Anghinah R, Kanda PAM, Jorge MS, Melo ACP. Eletrencefalograma quantitativo e topográfico (mapeamento cerebral): estudo do padrão normal para uma população adulta. Arq. Neuro-Psiquiatr. 1998;56,1:59-63.

19 - Mota MP. Biological Theories of aging. Rev. Port. Ciên. Desp. 2004;4:81-110.

20 - Lagerlund TD, Worrell GA. EEG source localization (Model-Dependent and Model- Independent Methods). In Niedermeyer E, Silva FL (eds). Electroencephalography: basic principles, clinical applications, and related fields, 5th ed, 2005:829-844.

21 – Velde TV, Woollacott M. Non-visual spatial tasks reveal increased interactions with stance postural control. Brain Res. 2008;1208:95-102.

22 – Wickens C, Kramer A, Vanasse L, Donchi E. Performance of concurrent tasks: a psychophysiological analysis of the reciprocity of information-processing resources. Sci. 1983;221,4615:1080-1082.

23 – Little CE, Woollacott M. Effect of attentional interference on balance recovery in older adults. Exp Brain Res. 2014;232,7:2049-2060.

24 – Johannsen L, Li KZH, Chechlacz M, Bibi A, Kourtzi Z, and Wing AM. Functional neuroimaging of the interference between working memory and the control of periodic ankle movement timing. Neuropsychol. 2013;51,11:2142–2153.

25 – Alvarez JA, Emory E. Executive function and the frontal lobes: a meta-analytic review. NeuropsycholHYPERLINK "https://www.ncbi.nlm.nih.gov/pubmed/16794878" Rev. 2006;16,1:17-42.

26 – Hamacher D, Herold F, Wiegel P, Hamacher D and Schega L. Brain activity during walking: a systematic review. Neurosci. Biobehav. Rev. 2015;57:310–327.

27 – Holtzer R, Mahoney JR, Izzetoglu M, Izzetoglu K, Onaral B and Verghese J. fNIRS study of walking and walking while talking in young and old individuals. J. Gerontol. A Biol. Sci. Med. Sci. 2011;66,8:879–887.

28 – Holtzer R, Epstein N, Mahoney JR, Izzetoglu M and Blumen HM. Neuroimaging of mobility in aging: a targeted review. J. Gerontol. A Biol. Sci. Med. Sci. 2014;69,11:1375–1388.

29 – Maidan I, Nieuwhof F, Bernad-Elazari H, Reelick MF, Bloem BR, Giladi N, et al. The role of the frontal lobe in complex walking among patients with Parkinson’s disease and healthy older adults: an fNIRS study. Neurorehabil. Neural Repair. 2016;30,10:963–971.

30 – Wagshula ME, Lucas M, Yed K, Izzetoglue M, Holtzer R. Multi-modal neuroimaging of dual-task walking: Structural MRI and fNIRSanalysis reveals prefrontal grey matter volume moderation of brainactivation in older adults. Neuroimage. 2019;189:745-754.

31 – Hamacher D, Herold F, Wiegel P, Hamacher D, Schega L. Brain activity during walking: A systematic review. Neurosci Biobehav Rev. 2015;57:310-327.

32 – Fraser SA, Li KZH, Berryman N, Desjardins-Crépeau L, Lussier M, Vadaga K, et al. Does Combined Physical and Cognitive Training Improve Dual-Task Balance and Gait Outcomes in Sedentary Older Adults? Front Hum Neurosci. 2017;10:688-700.

33 – Beurskens R, Steinberg F, Antoniewicz F, Wolff W, Granacher. Neural Correlates of Dual-Task Walking: Effects of Cognitive versus Motor Interference in Young Adults. Neural Plasticity. 2016;2016:1-3.

34 – Chaparro G, Balto JM, Sandroff BM, Holtzer R, Izzetoglu M, Motl RW, et al. Frontal brain activation changes due to dual-tasking under partial body weight support conditions in older adults with multiple sclerosis. J NeuroEng Rehabil. 2017;14,1:65.

35 – Mirelman A, Maidan I, Bernad-Elazari H, Shustack S, Giladi N, Hausdorff JM. Effects of aging on prefrontal brain activation during challenging walking conditions. Brain Cogn. 2017;115:41-46.

36 - Guyton & Hall - Tratado de Fisiologia Médica - 12ª Ed. 2011. p. 735-748.

37 – Colom R, Hua X, Martínez K, Burgaleta M, Román FJ, Gunter JL, et al. Brain structural changes following adaptive cognitive training assessed by Tensor-Based Morphometry (TBM). Neuropsychol. 2016;91:77–85.

38 – Schon K, Newmark RE, Ross RS, Stern CE. A Working Memory Buffer in Parahippocampal Regions: Evidence from a Load Effect during the Delay Period. Cereb Cortex. 2016;26,5:1965–1974.

39 – Mathewson KE, Lleras A, Beck DM, Fabiani M, Ro T, Gratton G. Pulsed out of awareness: EEG alpha oscillations represent a pulsed-inhibition of ongoing cortical processing. Front Psychol. 2011;2:99.

40 - Pfurtscheller G. Functional brain imaging based on ERD/ERS. Vision Res. 2001;41,10-11:1257–1260

41 - Kim J, Chung E, Lee B. A Study of Analysis of the Brain Wave with Respected to Action Observation and Motor Imagery : a Pilot Randomized Controlled Trial. J. Phys. Ther. Sc. 2013;25,7:779–782, 2013.

42 - Romei V, Bauer M, Brooks JL, Economides M, Penny W, Thut G, Driver J et al. Causal evidence that intrinsic beta-frequency is relevant for enhanced signal propagation in the motor system as shown through rhythmic TMS. Neuroimage. 2016;1,126:120–130.

43 – Jost K, Bryck RL, Vogel EK, Mayr U. 2011. Are old adults just like low working memory young adults? Filtering efficiency and age differences in visual working memory. Cereb Cortex. 2011;21,5:1147–1154.

44 – Sander MC, Werkle-Bergner M, Lindenberger U. Amplitude modulations and inter-trial phase stability of alpha-oscillations differentially reflect working memory constraints across the lifespan. Neuroimage. 2012;59,1:646-54.

45 – Sander MC, Lindenberger U, Werkle-Bergner M. Lifespan age differences in working memory: A two-component framework. Neurosc Biobehav Rev. 2012;36,9:2007-2033.

46 - Pfurtscheller G. Functional brain imaging based on ERD/ERS. Vision Res. 2001;41,10-11:1257–1260

47 - Kim J, Chung E, Lee B. A Study of Analysis of the Brain Wave with Respected to Action Observation and Motor Imagery : a Pilot Randomized Controlled Trial. J. Phys. Ther. Sc. 2013;25,7:779–782, 2013.

48 - Romei V, Bauer M, Brooks JL, Economides M, Penny W, Thut G, Driver J et al. Causal evidence that intrinsic beta-frequency is relevant for enhanced signal propagation in the motor system as shown through rhythmic TMS. Neuroimage. 2016;1,126:120–130.

49 – Veldhuizen RJ1, Jonkman EJ, Poortvliet DC. Sex differences in age regression parameters of healthy adults–normative data and practical implications. Electroencephalogr Clin Neurophysiol. 1993;86,6:377-84.

50 – Toledo DR, Barela JA, Manzano GM, Kohn AF. Age-related differences in EEG beta activity during an assessment of ankle proprioception. Neurosci Lett. 2016;622:1-5.

51 – Hübner L, Godde B, Voelcker-Rehage C. Acute Exercise as an Intervention to Trigger Motor Performance and EEG Beta Activity in Older Adults. Neural Plasticity. 2018:12-23.

52 - Goldberg E. O cérebro executivo: Lobos Frontais e a Mente Civilizada. Rio de Janeiro: Ed. Imago; 2002.

53 - Luft C, Andrade A. A pesquisa com EEG aplicada à área de aprendizagem motora. Rev. Port. Cien. Desp. 2006;6,1:106-115.

54 - Hatfield BD, Haufler AJ, Hung TM, Spalding TW. Electroencephalographic Studies of Skilled Psychomotor Performance. J. Clin. Neurophysiol. 2004;21,3:144- 156.

55 - Etnier JL, Salazar W, Landers DM, Petruzzello SJ, Han M, Nowell P. The influence of physical fitness and exercise upon cognitive functioning: a meta-analysis. J Sport Exercise Psychol. 1997;19,3:249-74.

56 - Haufler AJ, Spalding DL, Santa Maria DL, Hatfield BD. Neuro-Cognitive activity during a self-paced visuospatial task: comparative EEG profiles in marksmen and novice shooters. Biol. Psychol. 2000;53,2-3:131-160.

57 - Debaere F, Swinnen SP, Beatse E, Sunaert S, Van Hecke P, Duysens J. Brain areas involved in interlimb coordination: a distributed network. Neuroimage. 2001;14,5:947–958.

Figures

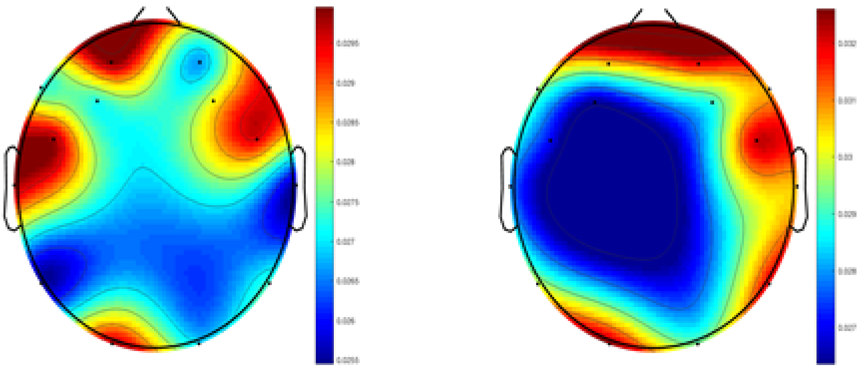

Figure 1

mapping of alpha waves during the performance of the simple and complex tasks respectively. There was approximately symmetrical activation in the right and left hemispheres in part A (simple task), while a predominance of activation in the frontal area and right hemisphere in part B (complex task).

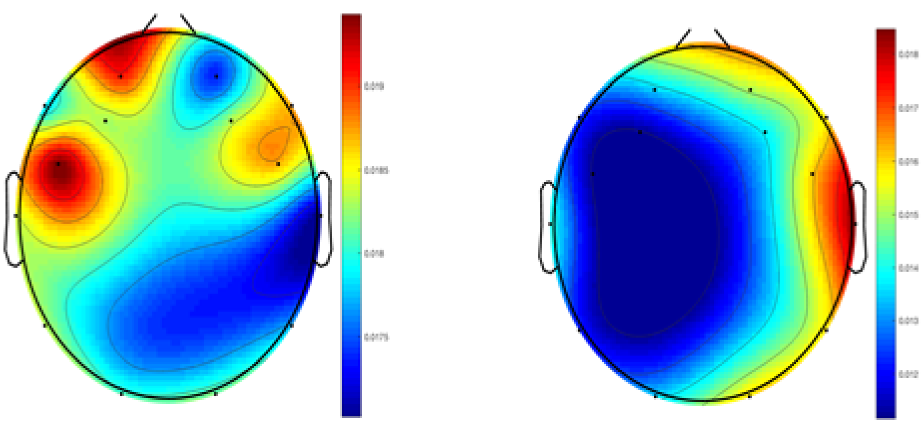

Figure 2

the beta wave behavior was observed while performing parts A and B of the DT activity. Greater activation was found in the left hemisphere in part A (simple task), while a predominance of activation in the right hemisphere in part B (complex task).