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Age-related differences in visual P300 ERP during dual-task postural balance

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Abstract— **Standing and concurrently performing a cognitive task is a very common situation in everyday life. It is associated with a higher risk of falling in the elderly. Here, we aim at evaluating the differences of the P300 evoked potential elicited by a visual oddball paradigm between healthy younger (< 35 y) and older (> 64 y) adults during a simultaneous postural task. We found that P300 latency increases significantly ($p < 0.001$) when the elderly are engaged in more challenging postural tasks; younger adults show no effect of balance condition. Our results demonstrate that, even if the elderly have the same accuracy in odd stimuli detection as younger adults do, they require a longer processing time for stimulus discrimination. This finding suggests an increased attentional load which engages additional cerebral reserves.**

Clinical relevance— **Here, we demonstrated the interaction between incoming visual stimuli and postural task in the elderly. Our findings may help predicting the risk of falling in the elderly and pave the way for future neural-based interventions.**

I. INTRODUCTION

Falls are one of the most common cause of morbidity and mortality in the elderly. Falls increase due to a combination of age-related risk factors. Main contributors are the deteriorating physical functions and the declining attentional reserve. In the elderly, additional cortical areas are often recruited to accomplish tasks which are highly automatized and require more focused cortical activation than in younger people, a phenomenon known as "compensatory cognitive scaffolding" [1]. This phenomenon was associated to an increase of electroencephalography (EEG) power in the delta band during postural tasks [2], [3]. Older adults show a significant reduction in the ability to perform a postural and a cognitive task simultaneously compared to younger adults [4]. Dual-task paradigms represent a well established way of examining competing resources during simultaneous execution of a cognitive and a motor task. The impact of the attentional demand is generally identified through the behavioral performance of the subject during a cognitive task [3] (e.g., a slower reaction time), or by analysing kinematic variables related to postural control, such as instability of the center of pressure [5][6]. However, the possibility to identify neural correlates of visual attention during postural tasks may provide additional insights of the underpinning mechanisms of loss of balance and pave the way for potential neural-based interventions.

P300 event-related potential (ERP) to infrequent visual stimuli may represent a good candidate to highlight cognitive load in dual-task postural balance [7]. P300 amplitude is proportional to the amount of attentional resources devoted to a given task. P300 latency measures the stimulus classification speed and is likely to reflect the neural processing of attention allocation. Thus, P300 ERP represents a reliable assessment of the "cognitive efficiency" of a subject—i.e., how well her/his central nervous system (CNS) processes incoming information. P300 has mainly be deployed in dual-tasking during walking in ageing subjects [8][9] or people with neurological disorders [10][11]. Since knowledge on neural correlates during dual-task balancing is scarce [2][12], and none of them is focused on ERP changes associated with attentional demands in postural tasks; we compare the P300 evoked response of healthy younger and older adults during a concurrent dual-task (visual oddball task and a postural task) in different balance conditions. Our hypothesis is that the elderly may devote less attentional resources to the oddball task, being attention split between the cognitive and postural task, and show longer processing time to discriminating odd stimuli when engaged in keeping balance. From a clinical perspective, this knowledge may provide the neural basis for rehabilitative/assistive interventions during upright standing in the elderly.

II. METHODS

A. Participants

Nine healthy right-handed elderly ([64-76] y) and eight healthy right-handed younger ([24-34] y) adults were recruited. More detailed information on the choice of the age range for the two groups and on the inclusion and exclusion criteria can be found in [12]. This study was carried out in accordance with the recommendations of the Ethics Committee of the Teaching Hospital of Padua, Italy (protocol number AOP2025). All subjects signed written informed consent.

B. Experimental protocol and data acquisition

The experimental protocol consisted of a dual-task experiment in which participants were asked to perform a balance task in different conditions, together with a 2-stimulus visual oddball task. Participants were standing in front of a black screen, instructed to stare at it. During the oddball task, the participants were asked to mentally count the number of

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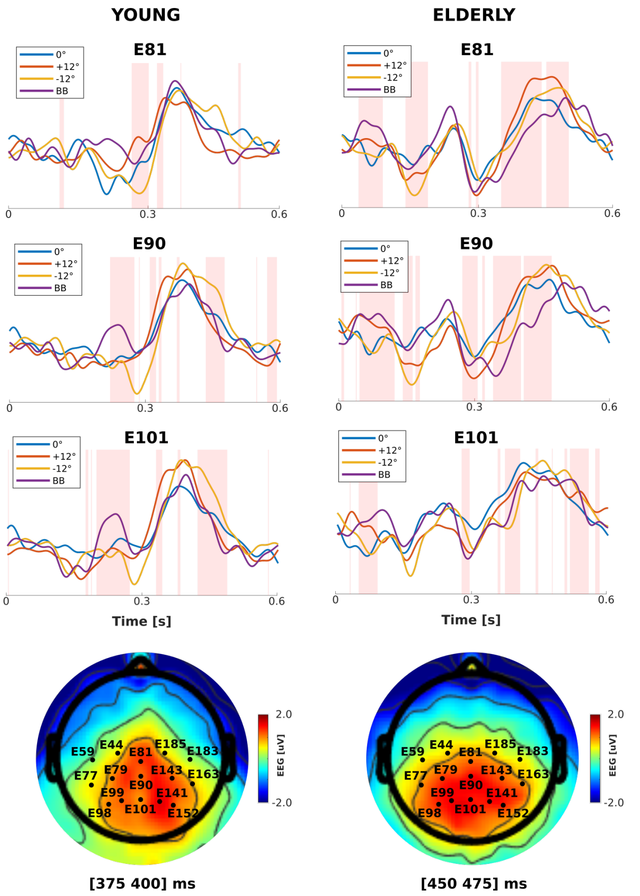

Fig. 1. Event related potential (ERP) waveforms on the mid-line E81, E90 and E101 electrodes for young adults (left) and elderly (right) during the oddball task while keeping balance on a 0° plane (blue), on a $+12°$ (red) or a $-12°$ (yellow) inclined plane, and on a balance board (violet). Red bars correspond to time periods in which the ERP waveforms of the different balance conditions differ significantly ($p < 0.05$). Average 204-channel topographic maps of the two age groups are shown in the time window in which the P300 component was detected. The locations of the centro-parietal electrodes considered for the ERP analysis are also shown.

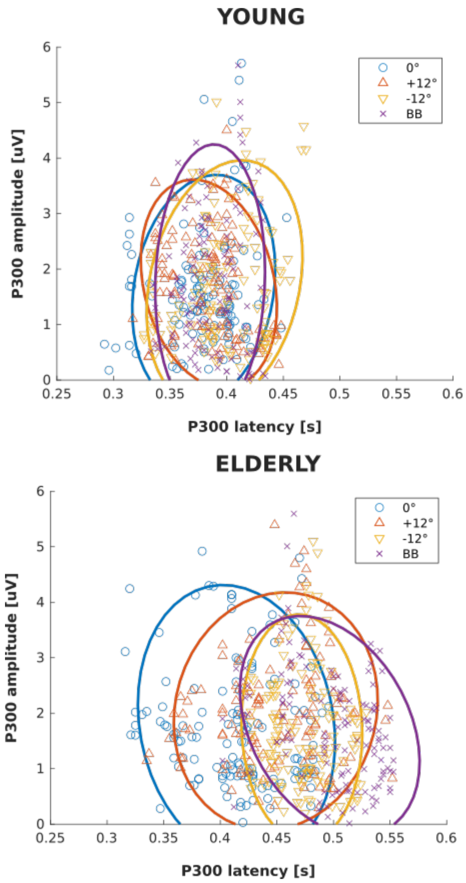

Fig. 2. Scattergrams of P300 amplitude and latency from the main centro-parietal channels in all the balance conditions (0° plane, $+12°$ inclined plane, $-12°$ inclined plane, balance board) for the young and elderly groups, respectively. Ellipses represent the contour of the best-fitting Gaussian containing the 86% of the data.

odd stimuli (i.e., a 3 cm^2 yellow square in the center of the black screen) that were presented, while ignoring the repetitive stimuli (i.e., a 3 cm^2 red square in the center of the black screen). Each stimulus lasted 500 ms and the inter-stimulus interval was chosen randomly from 500 ms to 1 s between each pair of consecutive stimuli. Each oddball trial consisted of a sequence of 100 stimuli, of which about the 80% were repetitive stimuli, for a duration of about 3 minutes. Four different balance conditions were presented: i) standing upright on ground-level (0°); ii) standing upright on a surface inclined at +12°; iii) standing upright on a surface inclined at -12°; iv) keeping balance on the 50 cm x 50 cm 1 degree-of-freedom wooden balance board (BB) with a total of 24° ($\pm 12°$) front-to-back tilt.

During each trial, 256 channels EEG was recorded in an electrically shielded room (Electrical Geodesic Inc., Eugene, OR, USA). Electrode-skin impedances were maintained below 40 $k\Omega$. The recordings were sampled at 500 Hz, referenced to Cz (10/10 system). Data used in this research were collected as part of a larger project, which includes electroencephalography, electromyography, and motion data [12].

C. EEG pre-processing

EEG data were zero-phase-high-pass-filtered above 1 Hz. Noisy channels were interpolated using the nearest-neighbor spline method. Epochs containing non-stereotyped artifacts, eye blinks and eye movements were removed from further analysis. Data were cleaned from remaining physiological artifacts through a Principal Component Analysis (PCA)-informed Independent Component Analysis (ICA) algorithm implemented in EEGLAB. We refer the reader to [12] for further details on data pre-processing.

In this work, EEG data were further filtered using a 6th order zero-phase Butterworth low-pass filter below 24 Hz and re-referenced using an average reference. For the following processing, we focused the analysis on the main EEG centro-parietal channels in the HydroCel Geodesic Sensor net configuration, thus the electrodes E59, E44, E81, E185, E183, E77, E79, E90, E143, E163, E98, E99, E101, E141, E152.

D. ERP analyses

For ERP analysis, EEG epochs were extracted from the continuous dataset and time-locked from -500 to 600 ms

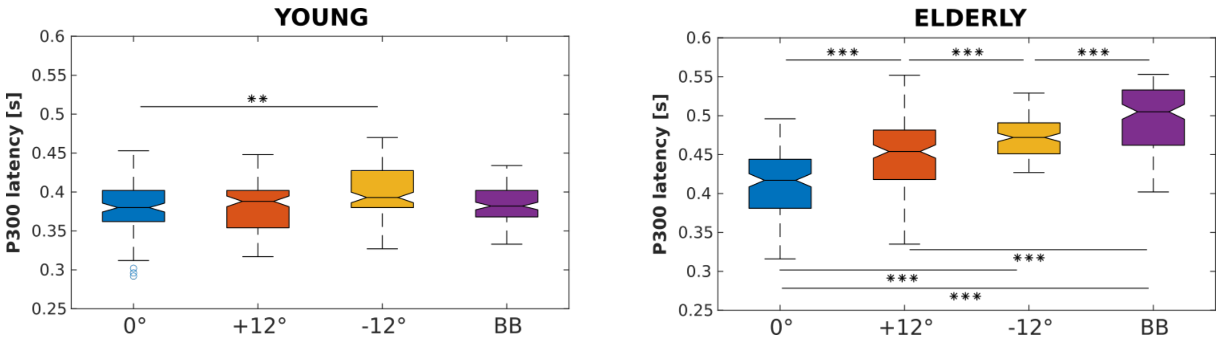

Fig. 3. Notched box plots of P300 latency for young adults (left) and elderly (right) in different balance conditions (0° plane, $+12°$ inclined plane, $-12°$ inclined plane, balance board). Outliers are marked by circles. Statistically significant differences between conditions are also reported.
$^{**}p < 0.01$, $^{***}p < 0.001$

relative to the onset of each visual stimulus. Averaging of the epochs belonging to the same trial was then performed for odd and repetitive stimuli separately. Averaged epochs were baseline corrected for the interval from -500 ms to 0 ms with respect to stimulus onset. P300 peaks were found algorithmically as the most positive or negative point with zero-slope on the curve in the range $300 - 600$ ms from stimulus onset. The correctness of the P300 peaks identified with this method was confirmed for each subject by an expert neurologist (ADF) and two bio-engineers (MR and EF) through the visual inspection of EEG time-courses and topographic maps.

To highlight ERP differences between the two groups and evaluate the effect of balance condition, a 3-factor (2 age groups, 4 balance conditions, 15 electrodes) analysis of variance (ANOVA) was performed on the P300 amplitude and latency data of the considered centro-parietal EEG channels, with $p < 0.05$ for a significant difference. Bonferroni corrected post-hoc tests ($p < 0.01$ for significant differences) were conducted for age group and balance condition to identify comparisons that were statistically significant. Normality of P300 amplitude and latency data was previously checked using the one-sample Kolmogorov-Smirnov test ($p > 0.05$).

III. RESULTS

All participants showed high accuracy in counting the number of odd stimuli (healthy young 100 ± 0.0% and healthy older adults 99.2 ± 0.4%). Figure 1 shows the grand-average ERP waveforms for each balance condition in the centro-parietal mid-line electrodes (E81, E90, E101) for young adults and elderly, together with their corresponding topographic maps. An evident positive peak can be seen in all the electrodes and for all the conditions in the range $300 - 600$ ms from stimulus onset. Elderly are characterized by a longer P300 latency (E81: 0.417 ± 0.04 ms, E90: 0.412 ± 0.05 ms, E101: 0.414 ± 0.04 ms) compared to young adults (E81: 0.375 ± 0.04 ms, E90: 0.376 ± 0.03 ms, E101: 0.380 ± 0.03 ms), while no difference in P300 amplitude emerged. An increase of latency emerges only for the elderly in the more challenging balance conditions, particularly over E81 and E90 electrodes. A statistical comparison of the ERP waveforms was performed using a one-way ANOVA on the time-series of the mid-line electrodes. The results highlight a statistically significant effect of the balance condition after 300 ms from stimulus onset for the elderly population. Figure 2 shows the distribution of the P300 features of all the subjects in all the centro-parietal electrodes considered for the statistical analysis. The ellipses represent the contour of the best-fitting Gaussian distribution containing 86% of the data for each of the balance condition. This representation better highlights the effect of the balance condition on the ERP component. In the young adults, the ellipses of all the conditions almost perfectly overlap for P300 amplitude and latency. In the elderly, the distributions of P300 shows a clear shift towards higher latencies with the increase of balance challenge (i.e., from level ground standing to inclined planes standing and dynamic balance).

From the statistical analysis of variance, no significant effect of aging ($p > 0.05$) or balance condition ($p > 0.05$), nor of their interaction ($p > 0.05$), was found for the P300 amplitude data. Only a statistically significant effect of electrode location emerged ($p < 0.001$). P300 latency data were significantly affected by both age ($p < 0.001$) and balance condition ($p < 0.001$), as well as by their interaction ($p < 0.001$), while no significant effect of electrodes location emerged ($p > 0.05$). Figure 3 shows the notched box plots of P300 latency for young and elderly in the four different balance conditions. A significant increase in P300 latency was found in the elderly from 0° level ground standing (0.414 ± 0.04 ms), to standing on a $+12°$ inclined plane (0.449 ± 0.04 ms) and on a $-12°$ inclined plane (0.472 ± 0.03 ms), with highest latency during the dynamic balance task (0.497 ± 0.04 ms). Conversely, the population of young adults does not show any trend in P300 latency with balance condition, except for a significant difference ($p < 0.01$) between level ground standing (0.379 ± 0.03 ms) and the $-12°$ inclined plane condition (0.398 ± 0.04 ms). A slight reduction of P300 amplitude in the $-12°$ inclined plane (1.73 ± 1.03) and on the balance board (1.77 ± 0.99) was also detected in the elderly compared to level ground (1.92 ± 1.25) and $+12°$ inclined plane (2.03 ± 1.07), even if not statistically significant.

IV. DISCUSSION

The goal of this study was to evaluate the differences of the brain response between healthy younger and older adults when performing an attentional demanding task concurrently with a postural task. The elderly required longer processing time for the discrimination of the odd stimuli since their cerebral reserve are already engaged in keeping balance – i.e., P300 latency is significantly higher when they are engaged in more challenging balance tasks. Our previous study [12] revealed a higher mid-line fronto-central theta rhythms during single-task balance in the elderly, a neural signature of focused attention. P300 amplitude was not affected by balance condition, suggesting that elderly present an unaltered stimulus detection and focused attention capability during the oddball task, as demonstrated by the correct counting of the number of odd stimuli. Conversely, young adults' P300 components are not affected by any balance task. Future studies should consider a more complete analysis on the whole ERP waveform to deepen our understanding on the age-related effect of dual-task balance on cognitive processing.

The elongation of processing time at cortical level that has been found in this study is paralleled and strengthened by previous EMG studies [13]. Elderly presented delayed motor activations and longer EMG latencies during dual-task balance, consistently with the observation that cortical potentials in the elderly appeared with a longer time lag compared to younger individuals. It also worth highlighting that this result differs from previous findings on dual-task walking studies, showing a significantly higher P300 latency during walking also in younger subjects [10]. The significant increase of P300 amplitude, found in the elderly during dual-task walking [8], was not found in dual-task standing in our study. These differences may suggest that while walking represent an attentional demanding task independently from the age, the capability of keeping upright standing is more severely affected by aging, requiring more neural resources devoted to the balance task for the elderly. For this reason, the need of methodologies to study the interaction between cognitive processes and upright balance maintenance is of paramount importance to deepen our understanding on CNS changes induced by aging and could be used as proxy to estimate the available cognitive reserve in elderly subjects [14].

In conclusion, in this protocol we studied the interaction of incoming visual stimuli and balance task in the elderly. This study significantly strengthens the hypothesis of an increased cognitive demand during static and dynamic postural balance in the elderly. In future work, a single-trial analysis of the ERP features exploiting the latest advancements in machine learning [15], may be used in clinical practice to integrate state-of-the-art biomechanical evaluations. Indeed, the development of more comprehensive assessment methods of balance maintenance may help predicting the risk of falling of the elderly [16] and possibly preventing falls.

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REFERENCES

[1] P. A. Reuter-Lorenz and D. C. Park, "How does it stac up? revisiting the scaffolding theory of aging and cognition," *Neuropsychology review*, vol. 24, no. 3, pp. 355–370, 2014.

[2] R. A. Ozdemir, J. L. Contreras-Vidal, and W. H. Paloski, "Cortical control of upright stance in elderly," *Mechanisms of ageing and development*, vol. 169, pp. 19–31, 2018.

[3] D. C. Chan, T. W. Wong, F. F. Zhu, C. Cheng Lam, W. R. Young, C. M. Capio, and R. S. Masters, "Investigating changes in real-time conscious postural processing by older adults during different stance positions using electroencephalography coherence," *Experimental aging research*, vol. 45, no. 5, pp. 410–423, 2019.

[4] M. Rubega, R. Di Marco, M. Zampini, E. Formaggio, E. Menegatti, P. Bonato, S. Masiero, and A. Del Felice, "Muscular and cortical activation during dynamic and static balance in the elderly: A scoping review," *Aging Brain*, vol. 1, p. 100013, 2021.

[5] T. Coelho, Â. Fernandes, R. Santos, C. Paúl, and L. Fernandes, "Quality of standing balance in community-dwelling elderly: Age-related differences in single and dual task conditions," *Archives of gerontology and geriatrics*, vol. 67, pp. 34–39, 2016.

[6] T. Siragy and J. Nantel, "Quantifying dynamic balance in young, elderly and parkinson's individuals: a systematic review," *Frontiers in aging neuroscience*, vol. 10, p. 387, 2018.

[7] S. C. I. Pavarini, A. G. Brigola, B. M. Luchesi, É. N. Souza, E. S. Rossetti, F. J. Fraga, L. P. C. Guarisco, M. Terassi, N. A. Oliveira, P. Hortense *et al.*, "On the use of the p300 as a tool for cognitive processing assessment in healthy aging: a review," *Dementia & neuropsychologia*, vol. 12, pp. 1–11, 2018.

[8] B. R. Malcolm, J. J. Foxe, J. S. Butler, and P. De Sanctis, "The aging brain shows less flexible reallocation of cognitive resources during dual-task walking: a mobile brain/body imaging (mobi) study," *Neuroimage*, vol. 117, pp. 230–242, 2015.

[9] R. Beurskens, F. Steinberg, F. Antoniewicz, W. Wolff, and U. Granacher, "Neural correlates of dual-task walking: effects of cognitive versus motor interference in young adults," *Neural plasticity*, vol. 2016, 2016.

[10] I. Maidan, F. Fahoum, S. Shustak, E. Gazit, D. Patashov, D. Tchertov, N. Giladi, J. M. Hausdorff, and A. Mirelman, "Changes in event-related potentials during dual task walking in aging and parkinson's disease," *Clinical Neurophysiology*, vol. 130, no. 2, pp. 224–230, 2019.

[11] M. de Tommaso, K. Ricci, A. Montemurno, E. Vecchio, and S. Invitto, "Walking-related dual-task interference in early-to-middle-stage huntington's disease: An auditory event related potential study," *Frontiers in psychology*, vol. 8, p. 1292, 2017.

[12] M. Rubega, E. Formaggio, R. Di Marco, M. Bertuccelli, S. Tortora, E. Menegatti, M. Cattelan, P. Bonato, S. Masiero, and A. Del Felice, "Cortical correlates in upright dynamic and static balance in the elderly," *Scientific Reports*, vol. 11, no. 1, pp. 1–15, 2021.

[13] M. Błaszczyszyn, A. Szczesna, and K. Piechota, "semg activation of the flexor muscles in the foot during balance tasks by young and older women: A pilot study," *International journal of environmental research and public health*, vol. 16, no. 22, p. 4307, 2019.

[14] C. Pettigrew and A. Soldan, "Defining cognitive reserve and implications for cognitive aging," *Current neurology and neuroscience reports*, vol. 19, no. 1, p. 1, 2019.

[15] A. J. Solon, V. J. Lawhern, J. Touryan, J. R. McDaniel, A. J. Ries, and S. M. Gordon, "Decoding p300 variability using convolutional neural networks," *Frontiers in human neuroscience*, vol. 13, p. 201, 2019.

[16] S. Pizzamiglio, H. Abdalla, U. Naeem, and D. L. Turner, "Neural predictors of gait stability when walking freely in the real-world," *Journal of neuroengineering and rehabilitation*, vol. 15, no. 1, pp. 1–11, 2018.