# Hyperexcitability in Older Adults with Elevated Beta-Amyloid

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# Hyperexcitability in older adults with elevated beta-amyloid

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**Abstract**

Background: Growing evidence links beta-amyloid (Aβ) and neuronal hyperexcitability in preclinical mouse models of Alzheimer's disease (AD). The aim of this study was to compare neuronal excitability between cognitively normal amyloid positive (CNAβ+) and those without elevated amyloid (CNAβ-) older adults. We hypothesized CNAβ+ participants would show hyperexcitability, indexed by greater peak P3 event-related potential peak amplitude, shorter peak latency, and changes in event-related power, compared to CNAβ-.

Methods: CNAβ+ participants (n = 17, age: 73 ± 5, 11 women, MOCA scores 26 ± 2) and 17 CNAβ- participants group-matched for age, sex, and MOCA completed the a working memory task (n-back with n = 0, 1, 2) test while wearing a 256-channel EEG net. P3 peak amplitude and latency of the nontarget, target and task difference (nontarget – target), and event-related power, extracted from Fz (main outcome), Cz, and Pz were compared between groups using linear mixed models. Mean Aβ standard uptake value ratios (SUVR) were correlated with P3 amplitude and latency using Pearson r.

Results: P3 peak amplitude of the task difference ($p = 0.048$) and P3 peak latency of non-targets trials ($p = 0.006$) at Fz differed between groups. Similarly, power was lower in the delta band ($p = 0.04$) for nontargets at Fz in CNAβ+ participants. CNAβ+ participants also demonstrated higher theta and alpha power in channels at Cz and Pz, but no changes in P3 ERP. Strong correlations were found between mean Aβ SUVR and latency of the 1-back ($r = -0.69$; $p = 0.003$) and 2-back ($r = -0.69$; $p = 0.004$) of the task difference at channel Fz in the CNAβ+ group.

Conclusions: Our pilot data suggests that elevated amyloid in cognitive normal older adults is associated with hyperexcitability in P3 ERP. Further research is warranted to determine the validity of ERP in predicting clinical, neurobiological, and functional manifestations of AD.

Keywords: event-related potentials, electro-encephalography, working memory, older adults, preclinical, beta-amyloid (Min.5-Max. 10)

## 1 Introduction

Alzheimer's disease (AD) is increasingly viewed as a disconnection syndrome leading to disturbance of the synaptic excitation/inhibition balance in the brain.(1, 2) Even in the preclinical phase when no cognitive impairments are apparent,(3) beta-amyloid (Aβ) oligomers and Aβ plaques show associations with this excitation/inhibition imbalance and altered activity of local neuronal circuits and large-scale networks.(4) Preclinical mouse models of AD support the notion that this imbalance causes hyperactivity in hippocampal and cortical neurons and reductions of slow-wave oscillations, even before the appearance of Aβ plaques.(4) Such hyperactivity shifts the normal excitation/inhibition balance towards neuronal hyperexcitability, mediated through both an increase in excitation of synaptic glutamatergic tone and decreased GABAergic inhibition.(4) This relative neuronal hyperexcitability in turn leads to excitotoxicity,(5) amplification of synaptic release of Aβ,(6) and ultimately to further neurodegeneration and neuronal silencing mediated by concomitant tau accumulation.(7) Previous studies have explained this hyperexcitability as a physiological compensation for the increased Aβ burden in preclinical AD,(8-11) wherein the accumulation

of Aβ deposits results in neural recruitment, up until a certain threshold when the compensatory mechanisms fail. The hyperexcitability is then followed by hypoexcitability due to functional neuronal silencing in clinically diagnosed AD.(7)

Electro-encephalography (EEG) offers insights into postsynaptic activity of pyramidal cells and may therefore be useful for evaluating the impact of Aβ deposits on neuronal excitability in the preclinical and clinical stages of AD in humans.(12) The results of a systematic review show consistent evidence of hypoexcitability, expressed as reduced power in the high frequency bands in AD, and lower amplitude and larger latency of event-related potentials (ERP).(12) The associations between Aβ and neuronal excitability in mild cognitive impairment (MCI) and preclinical AD are less clear. One resting-state EEG study including cognitively normal (CN) older adults with subjective memory impairments found a non-linear relationship between Aβ and delta power, in those individuals who showed signs of neurodegeneration, but not those with normal-appearing brain.(11) Another study did not show associations between power and Aβ load in CN older adults with subjective cognitive impairments.(13) Yet, CN older adults with increased Aβ load and subjective cognitive impairments exhibited greater connectivity in the alpha band and reduced connectivity in the beta band.(13) Studies evaluating excitability under cognitive load in the presymptomatic stages of AD are even more limited. Event-related spectral power in the alpha and beta bands extracted while doing a working memory task (2-back) was higher in older adults with unknown Aβ status who deteriorated in an 18-month follow-up assessment compared to CN participants who remained stable.(14) No study has explored the possible impact of Aβ on electrophysiology in CN older adults under cognitive load.

The P3 (or P300) is a positive ERP that appears at around 300 milli-seconds after stimulus onset. The amplitude of P3 is generally considered as a measure of resource allocation, particularly during working memory tests.(15) A larger P3 could therefore be interpreted as greater mental effort to devote to the task.[15] The latency of the P3 is thought to reflect the cognitive processes that follow categorization of a stimulus according to its relevance to the task.[16] If CN older adults with increased Aβ load exhibit hyperexcitability, P3 will result in greater amplitude and shorter latency.

The main aim of this study was to compare neuronal excitability during working memory tasks of incremental cognitive demand between CN older adults with and without increased Aβ load. We hypothesized that CN amyloid elevated (CNAβ+) participants will show hyperexcitability as manifested by (1) greater peak P3 amplitude and (2) shorter P3 peak latency. A second aim of the study was to compare event-related power between CNAβ+ and CN amyloid non-elevated (CNAβ-). We hypothesized lower power in the delta band in CNAβ+ due to early breakdown of slow-wave frequency bands shown in animal studies.(4) Since theta, alpha, and beta bands contribute to P3 amplitude,(17) we also explored changes in these bands in CNAβ+. Finally, we explored the association between Aβ uptake and P3 peak amplitude and latency.

## 2 Materials and Methods

### 2.1 Participants

All participants were recruited from the University of Kansas Alzheimer's Disease Center between 5/30/2018 and 7/20/2020. Participants were excluded if they (1) were currently taking steroids, benzodiazepines, or neuroleptics; (2) had a history of any

substance abuse; (3) had history of a neurological disorder; or (4) any contra-indications to PET or EEG. Inclusion criteria were (1) age 65 years or older; (2) understanding of all instructions in English; (3) informed consent; and (4) a previously administered amyloid PET scan of the brain. Cerebral amyloid burden was assessed using PET images, obtained on a GE Discovery ST-16 PET/CT scanner after administration of intravenous Florbetapir 18F-AV45 (370MBq) following a previously published protocol.(18) To determine Aβ status, three experienced raters interpreted all PET images independently and without reference to any clinical information, as previously described.(19) Raters followed a process that combined both visual and quantitative information to determine status as Aβ- vs Aβ+.(20, 21) Final status was determined by majority of the three raters. The median (Q1 – Q3) time between the PET scan and EEG assessment was 1111 (794 - 1675) days.

## 2.2 Procedure

### 2.2.1 Demographic and Clinical Information

In the interview, we recorded age, sex, and education. Participants also completed the Montreal Cognitive Assessment (MOCA) as a general screen of cognitive functions.(22) Normal cognition was confirmed after a clinical assessment at the University of Kansas Alzheimer's Disease Center that included the Clinical Dementia Rating(23) and Uniform Data Set neuropsychiatric battery.(24)

### 2.2.2 N-back Test

While being recorded using EEG, participants were shown a series of letters and instructed to press a button when the current stimulus is the same as the item presented n-positions back (Figure 1). In the n-back test, the cognitive load increases with each number, but the perceptual and motor demands remain the same. In this study, the 0-back, 1-back, and 2-back tests were administered (Figure 1). The 0-back test was used as control condition.(25, 26) The 1-back test requires the participant to passively store and update information in working memory. The 2-back test requires constant switching from the focus of attention to short-term memory.(25) Higher levels of difficulty require continuous mental effort to update information of new stimuli and maintain representations of recently presented stimuli.(27)

Participants sat in a comfortable chair at 26 inches in front of the computer screen with the center of the screen at eye level. White letters appeared on a black screen. Participants completed a practice trial of 7 nontargets and 3 targets prior to each test. These practice sessions were repeated until participants felt comfortable with the instructions. The actual test consisted of 60 trials that required a response by pressing the left mouse button (target, 33.3%) and 120 trials for which a response was not required (nontarget, 66.7%). Each letter was presented for 500 ms on the computer screen followed by a blank interstimulus interval for 1700 ms, with a random jitter of +/-50 ms. The allowed maximum response time was 2150 ms. The total task time was ~396 seconds. The number of correct responses (accuracy) and response times to the correct response trials were the main behavioral performance outcome measures.

*Insert Figure 1 about here*

### 2.2.3 P3 Event-related potential and event-related power

Continuous EEG was acquired using a Magstim EGI high-density system from 256 scalp electrodes, digitized at 1,000 Hz. Data were filtered from 0.50 to 30 Hz and online referenced to Cz using EGI software. All other EEG processing was done in EEGLab(28) and in ERPLab.(29) Electrodes around the face were first removed, leaving 183 electrode channels in the processing pipeline. Bad channels were removed through automatic identification and visual inspection of the EEG data. Various artifacts unrelated to cognitive functions, including ocular and muscular movement or cardiovascular signals, were identified and removed using independent component analysis. Stimulus-locked ERPs were extracted from the n-back tests and segmented into epochs of 100 ms before to 1000 ms after stimulus onset, and baseline corrected using the prestimulus interval. Epochs of incorrect and missed responses were removed from the analyses. Signals from bad electrodes were then interpolated using surrounding electrode data. Scalp locations and measurement windows for the P3 component were based on their spatial extent and latency after inspection of grand average waveforms. P3 peak amplitude and latency of the target, nontarget, and task effect response were considered main outcome variables. The task effect was calculated by subtracting the average ERP elicited from the targets from the average ERP elicited by nontargets (nontarget – target) for each participant. Therefore, a lower amplitude of task difference waveform reflects more neuronal activity. The P3 component time window was established between 250 ms and 650 ms for all three tests. Average event-related power was identified for four frequency bands: delta [2–4 Hz], theta [4–8 Hz], alpha [8–12 Hz] and beta [12–30 Hz].(30) Because of the prefrontal cortex involvement in working memory, we identified a priori Fz as the main channel, but also report the P3 ERP of channel locations Cz and Pz. Cz

was interpolated using the surrounding five channels after re-referencing offline to the linked mastoids. No participants were removed from the analyses because of artifacts.

### 2.2.4 Data Analysis

Descriptive analysis including mean (standard deviation), median (Q1 – Q3), and frequency count of participants' general, performance measures, and ERP data were performed as appropriate. Unpaired t-tests, Median tests, and Chi-square tests were used to compare descriptive variables and performance on cognitive tests. We conducted linear mixed models to determine P3 peak latency and power at channel Fz. We used a random intercept term with a subject-specific coefficient to adjust for correlation between measures within subjects. Group (CNAβ+ and CNAβ-) and n-back difficulty (0, 1, 2) were entered as main effects. Interaction effects of group*n-back were also examined. Bonferroni correction was applied for pairwise comparisons. Residual analysis was used to validate model assumptions. Variables were transformed to their log function when residuals were not normally distributed. We entered age, sex, education, and MOCA as potential covariates in a separate linear mixed model. These analyses were repeated for channels Cz and Pz. In addition, linear mixed models were employed to investigate the main effects of group and condition (n-back) on average event-related power in the delta, theta, alpha, and beta bands. The mean Aβ standard uptake value ratio (SUVR) and the SUVR of the six predefined regions (anterior cingulate, posterior cingulate, precuneus, inferior medial frontal, lateral temporal, and superior parietal cortex) were correlated with the P3 peak amplitude and latency of the task difference (nontarget – target) of each n-back test at channel Fz, Cz, and Pz using

Pearson r correlation coefficients. Variables < 0.05 were considered significant. Analyses were performed using SAS 9.4 and SAS Enterprise Guide 8.2.

## 3 Results

### 3.1 Participant Characteristics

We recruited 17 CNAβ+ (age: 73 ± 5; 11 (65%) women; MOCA: 26 ± 2) and 17 CNAβ- (age: 75 ± 6; 12 (71%) women; MOCA: 28 ± 2). MOCA scores ranged between 25 and 30. No differences were observed for age, sex, and MOCA scores between groups (**Table 1**).

We first calculated differences in behavioral outcomes on the n-back tests (Table 1). Linear mixed models showed no main group effects on response time ($p = 0.36$) and on accuracy ($p = 0.91$). The response times of the 0-, 1-, 2-back tests are also shown in **Figure 2**.

Insert table 1 about here

### 3.2 P3 grand average waveforms

Visual inspection of the grand average waveforms of the targets and nontargets at channel Fz of the CNAβ- group showed that the P3 amplitudes decrease with increased task difficulty (**Figure 2**; **Supplementary Table 1**). The task difference (nontarget – target) effect also decreases, with the target response being smaller in the 2-back test in the CNAβ- group. The latency

increased with task demand in the CNAβ- group. The scalp map of the peak P3 response in the CNAβ- showed activation within the frontal lobe, with more focal activation as the task load increases. Such load effects were not observed in the CNAβ+ group (**Figure 2**; **Supplementary Table 1**).

Linear mixed model analysis showed a main effect of group ($p = 0.048$; $p = 0.05$ after adjusting for age, sex, and MOCA scores), but not of n-back condition ($p = 0.27$) on the P3 peak amplitude of the task difference (nontarget – target) at channel Fz. No other effects were found for peak amplitude.

Significant group effects were found for P3 latency for nontargets (non-adjusted $p = 0.006$; adjusted $p = 0.006$) at channel Fz. The P3 latency of the task difference was sensitive to changes in cognitive demand (non-adjusted $p = 0.047$; adjusted $p = 0.05$).

No other effects were found at the other channels Cz and Pz, except for peak latency of the nontarget at channel Cz that produced significant group effects (non-adjusted $p = 0.04$; adjusted $p = 0.04$).

*Insert Figure 2 about here*

### 3.3 P3 event-related power

Power in each of the frequency bands for each of the three n-back conditions at channels Fz, Cz, and Pz is detailed in **Supplementary Table 2**.

At channel Fz, CNAβ+ participants exhibited lower power in the delta band for non-targets (unadjusted p = 0.04; adjusted p = 0.08, with age (p = 0.01) and MOCA scores (p = 0.007) contributing significantly to the model).

At channel Cz, CNAβ+ participants exhibited higher power in the theta band for the task difference effect (unadjusted p = 0.05; adjusted p = 0.09). In addition, higher power was observed in the alpha band for non-targets (unadjusted p = 0.05; adjusted p = 0.03), for targets (unadjusted p = 0.04; adjusted p = 0.03), and the task difference (unadjusted p = 0.03; adjusted p = 0.09, with age (p = 0.02) contributing significantly to the model).

At channel Pz, CNAβ+ participants exhibited higher power in the theta band for non-targets (unadjusted p = 0.05; adjusted p = 0.07) and task difference effect (unadjusted p = 0.03; adjusted p = 0.11). Likewise, higher power in the alpha band (unadjusted p = 0.03; adjusted p = 0.03)

Analyses of the beta band did not produce significant effects.

### 3.4 Correlation between amyloid and P3 ERP

Visual exploration of the correlation table suggested stronger correlation between SUVR and latencies than with amplitudes (**Figure 3**). Pearson r correlation coefficients of 0.53 and higher were significant ($p<0.05$). Mean SUVR of the CNAβ+ group correlated negatively with P3 peak latency of the 1-back (r = -0.69; p = 0.003) and 2-back (r = -0.69; p = 0.004) at Fz. SUVR in the anterior cingulate cortex (r = -0.74; p = 0.009) and the inferior medial frontal lobe (r = -0.74; p = 0.001), posterior cingulate cortex (r = -0.72; p = 0.002) and precuneus (r = -0.64; p = 0.005) correlated strongly with P3 peak latency of the 1-back test at

channel Fz. Similarly, strong correlations were observed between SUVR in the posterior cingulate cortex (-0.84; p = 0.0001), precuneus (r = -0.68; p = 0.005), inferior medial frontal lobe (r = -0.59; p = 0.02), superior parietal lobe (r = -0.59; p = 0.02), anterior cingulate cortex (r = -0.56; p = 0.03), and lateral temporal lobe (r = -0.54; p = 0.04), with P3 peak latency of the 2-back test at channel Fz. Overall, the magnitude of correlations between SUVR and P3 peak amplitude and latency was smaller at channels Cz and Pz than at Fz in CNAβ+.

SUVR correlated with P3 peak amplitude of several n-back conditions in the CNAβ- group (Figure 3B). SUVR in the superior parietal cortex correlated negatively with P3 peak amplitude of the 0-back test at channel Fz (r = -0.69; p = 0.007) and of the 1-back test at channel Cz (r = -0.69; p = 0.006). SUVR of the posterior cingulate cortex correlated with P3 peak amplitude of the 1-back test at Pz (r = -0.58; p = 0.03). Mean SUVR correlated with peak P3 latency of the 2-back test at Fz (r = -0.56; p = 0.04) and at Cz (r -0.62; p = 0.01) and of the 1-back test at Pz (r = -0.69; p = 0.006). Similar magnitudes of correlations were observed for the subregions anterior cingulate cortex, inferior medial frontal lobe, posterior cingulate cortex, and precuneus.

*Insert Figure 3 about here*

## 4 Discussion

The goal of this study was to compare neuronal excitability during working memory of incremental cognitive demand between cognitively normal Aβ elevated older (CNAβ+) and those with no increased Aβ (CNAβ-). We demonstrated hyperexcitability in the P3 event-related potential (ERP) as well as changes in event-related power (lower power in the low frequency bands [delta]

and higher power in the mid-range frequency bands [theta, alpha]) in CNAβ+ adults. Cognitive load did not affect differences in P3 ERP between the two groups. In addition, we found strong correlations between Aβ deposits in cortical brain regions and P3 ERP. However, this hyperexcitability did not affect behavioral performance as no differences were found in accuracy and response times on the n-back test.

Combining our results with ERP studies in clinically diagnosed AD,(31, 32) our data suggest that the P3 ERP amplitude follows an inverse U-shaped distribution, with lower amplitudes in CNAβ-, larger amplitudes in CNAβ+, followed by lower amplitudes in AD. The greater amplitude and shorter latency of the P3 ERP to nontargets and targets in CNAβ+ individuals could reflect increased neural chatter (decreased noise dampening), with less focused activation of neurons in the frontal lobe to devote to the task.(15) The increased neural chatter also results in a smaller task difference (nontarget – target) effect. In clinically diagnosed AD, the lower P3 amplitudes reflect hypoexcitability due to neural silencing. Individuals with MCI either manifest no significant differences or smaller P3 amplitude compared to controls.(32) The reason for these equivocal findings may be that MCI marks the transition stage between CNAβ+ where hyperexcitability dominates, and AD where hypoexcitability dominates.

Similar U-shaped distributions were found in earlier studies investigating spectral power during resting state EEG. A previous study classified CN older adults with subjective memory complaints according to their Aβ burden (+ or -) and associated neurodegeneration (+ or -) evidenced by decreased brain glucose metabolism in their PET scans in four respective categories. A U-shaped distribution was found in delta power and an inverse U-shaped distribution in gamma power, most pronounced in those individuals with signs of neurodegeneration.(11) In addition, the presence of neurodegeneration was associated with a

decrease in lower frequency waves (delta) and increase in higher frequency waves (beta and gamma) in the fronto-central regions.(11) Yet, there were no associations between Aβ load and spectral power in the absence of neurodegeneration. Our study also demonstrated lower delta event-related power in the frontal midline channel, along with an increase in theta and alpha event-related power in the central and parietal midline channels in CNAβ+. The similarities in spectral power in the different frequency bands between the previous study(11) and ours imply that our group of CNAβ+ participants may have shown early signs of neurodegeneration. However, we cannot confirm this assumption as we did not formally assess neurodegeneration. Another potential explanation is that changes in power may exhibit earlier in the disease process (i.e., in Aβ+ with no neurodegeneration) under cognitive load as opposed to resting. Although no interaction effects of group by n-back were found, visual inspection of the P3 waveforms showed that the differences between CNAβ+ and CNAβ- were most obvious under highest cognitive load. However, our study may have been underpowered to elicit these differences statistically.

Our results suggest a direct link between average and regional Aβ burden and electrophysiological consequences, particularly in the frontal cortex in CNAβ+. Animal studies using mouse models of AD found hyperactive neurons exclusively around the Aβ plaques,(5) suggesting that Aβ exerts toxic effect on surrounding neurons and synapses, thereby disturbing their function and perhaps leading to dementia.(33) However, no causal inferences can be made from the results of our study. Longitudinal studies are required to identify the effect of Aβ burden on the relative postsynaptic excitation, and the role EEG P3 plays as a biomarker of pathophysiological, clinical, and functional decline.

Limitations of this study include the relatively small sample size and the large time interval between PET scan and EEG testing. We cannot rule out that some CNAβ- participants converted to CNAβ+. The projected conversion rates from Aβ- to Aβ+ is about 4% per year,(34) showing stability of cortical Aβ in the vast majority of older adults. Yet, our results should be interpreted with caution until confirmed in a longitudinal study with larger sample size. We chose the n-back test to test our hypotheses as working memory is regarded a core cognitive function sensitive to aging and early neurodegeneration upon which higher order cognitive skills, such as attention, decision making, and planning are built.(35) Our results are therefore unique to working memory cannot be generalized to other domains of cognitive functions that are relevant to AD.

## 5 Conclusion

Older adults with normal cognition and elevated beta-amyloid show neuronal hyperexcitability under cognitive load. This hyperexcitability may reflect increased neural chatter when attending to the task. Future studies are required to elucidate the causal effects between beta-amyloid depositions and neural excitability.

**List of abbreviations:**

Aβ, beta-amyloid; AD, Alzheimer's disease; CN, cognitively normal; EEG, electro-encephalography; MCI, Mild Cognitive Impairment, MOCA, Montreal Cognitive Assessment; ERP, event-related potential; ISI, interstimulus interval; PET, positron emission tomography; SUVR, standard uptake value ratio.

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## Availability of Data and Materials

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

## DECLARATIONS

### Ethics Approval and Consent to Participate

This study was approved by the Human Subjects Committee the University of Kansas Medical Center (#4461). Informed consent was obtained from all participants.

## Competing Interests

The authors declare that they have no competing interests.

## Authors' contributions

HD, KG, WB, JM, and JB conceptualized the study. HD, KL, PA administered the EEG assessments. HD, KG, and KL created the pipeline for EEG processing. HD and BE processed the EEG data. HD and JM created the statistical plan and conducted the statistical analyses. HD, KG, KL, WB, JM, JB, PA, and BE interpreted the results. HD wrote the first version of the manuscript. KG, KL, WB, JM, JB, PA, and BE reviewed and revised the manuscript. All authors read and approved the final manuscript.

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**Figure Legends**

Figure 1. Design of the n-back test. ISI = Interstimulus interval

Figure 2. Grand average waveforms with P3 peak scalp maps for the three n-back tests between CNAβ+ (top) and CNAβ- (bottom) at channel Fz. Behavioral response times are indicated by the computer mouse.

Figure 3. Pearson r correlations between beta-amyloid (Aβ) standard uptake value ratio and P3 event-related potential for each n-back test at channel Fz, Cz, and Pz. The color heat map shows the magnitude of the correlations in the positive (green) and negative (red) direction. Bolded values are significant ($p<0.05$)

Top panel A shows correlations for the cognitively normal, elevated (CNAβ+) group; Bottom panel B shows the correlations for the cognitively normal, non-elevated (CNAβ-) group.

Table 1. Comparison of descriptive, clinical, and performance variables between CNAβ+ and CNAβ-

Supplementary Table 1. P3 peak amplitude and latency, at Fz/Cz/Pz, across testing conditions of CNAβ+ and CNAβ-

Supplementary Table 2. Event-related power (μV/Hz2) at Fz/Cz/Pz, across testing conditions of CNAβ+ and CNAβ-. (Mean ± Std. Dev.)

# Figures

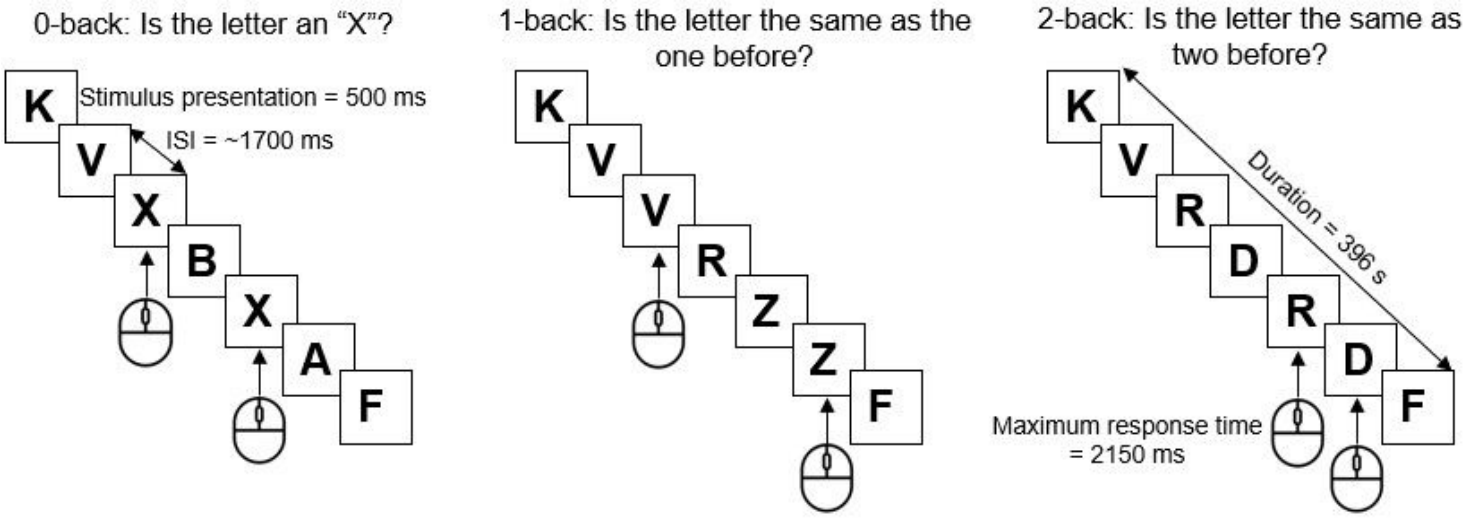


**Figure 1**

Design of the n-back test. ISI = Interstimulus interval

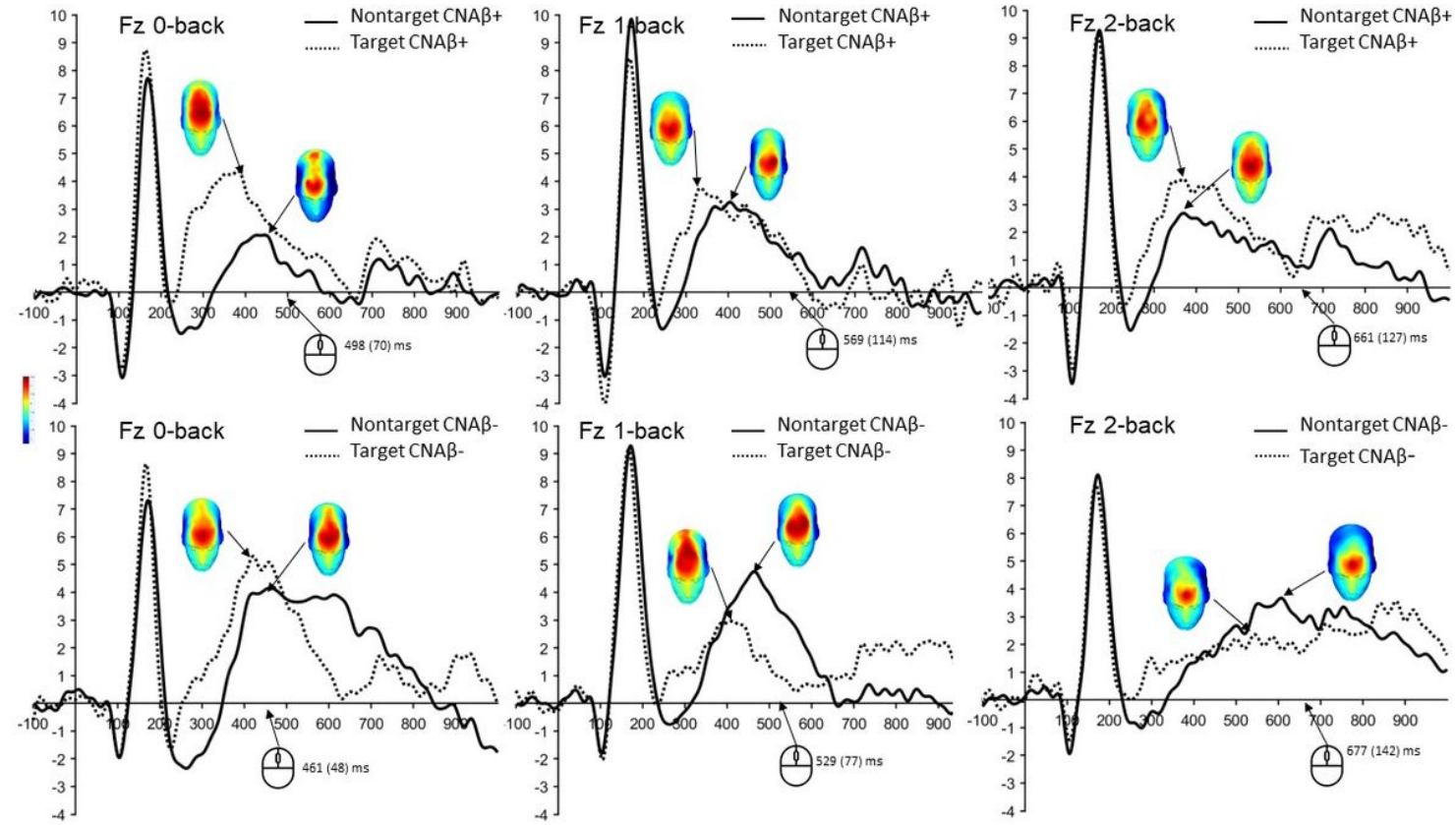


**Figure 2**

Grand average waveforms with P3 peak scalp maps for the three n-back tests between CNAβ+ (top) and CNAβ- (bottom) at channel Fz. Behavioral response times are indicated by the computer mouse.

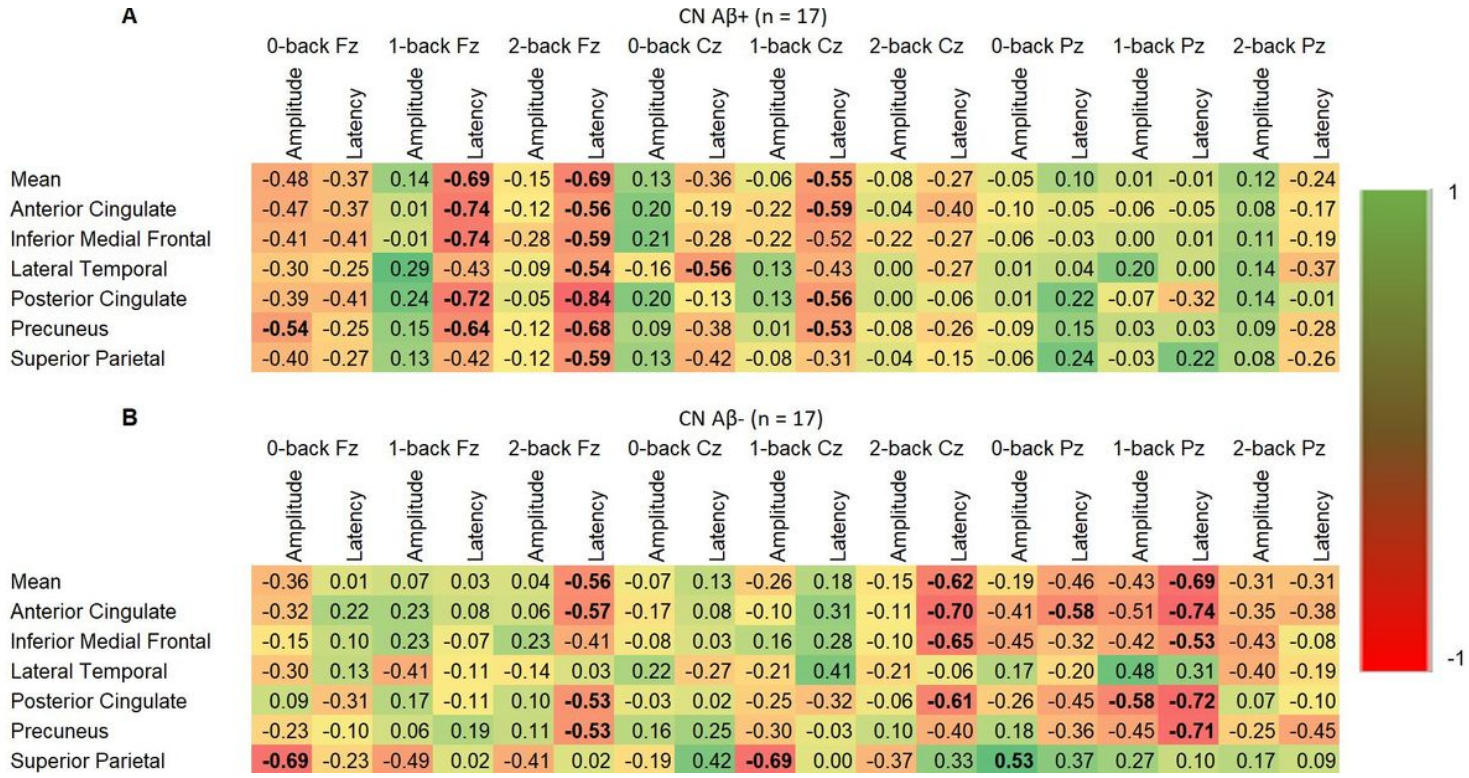


**Figure 3**

Pearson r correlations between beta-amyloid (Aβ) standard uptake value ratio and P3 event-related potential for each n-back test at channel Fz, Cz, and Pz. The color heat map shows the magnitude of the correlations in the positive (green) and negative (red) direction. Bolded values are significant ($p<0.05$) Top panel A shows correlations for the cognitively normal, elevated (CNAβ+) group; Bottom panel B shows the correlations for the cognitively normal, non-elevated (CNAβ-) group.

# Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarytable1.pdf
- Supplementarytable2.pdf
- Table1.pdf