

Delta frequency (0.5-3 Hz) is typically absent during the waking state of healthy adults and is associated with deep sleep (Schandry, 2016).

Beta frequency (14-30 Hz) is typically present when individuals are awake and mentally or physically active, or under psychological stress (Schandry et al., 2016).

Delta frequency (0.5-3 Hz) (Bachman & Bernat, 2018; Gunasekaran, Azizi, Van Wassenhove & Herbst, 2023; Uchida, Maloney & Feinberg, 1992)

Beta frequency (14-30 Hz) (Brovelli, Ding, Ledberg, Chen, Nakamura & Bressler, 2004; Liang, Zhang, Liu, Lou, Liu & Wang, 2020; Pesonen, Hämäläinen & Krause, 2007; Poppelaars, Harrewijn, Westenberg & Van der Molen, 2018; Tzagarakis, West & Pellizzer, 2015)

#### Alpha

As expected, the occipital alpha power was reduced in the AD and MCI groups compared to the HC group (D'Atri et al., 2021).

Slowing of alpha power may be an early sensitive indicator of the brain transitioning from normal physiological function to aging or its pathological state [10] (Liu et al., 2024). Lower power and synchronization of alpha oscillations have consistently been associated with neurodegenerative dementias, especially AD (Jeong, 2004; Lejko, Larabi, Herrmann & Aleman, 2020) [29, 37–39]. These decreases were found to correlate with lower cognitive scores [40, 41] (Lejko et al., 2020).

Among the most promising EEG markers are reduced alpha power (Cassani et al., 2017; Hatz et al., 2015; Musaeus et al., 2018) (Farina et al., 2020).

As expected, healthy ageing was associated with higher alpha power, both in amplitude (temporo-parietal areas) and connectivity (with frontal electrodes), which was increased in controls relative to patients, and in aMCI relative to AD (Farina et al., 2020).

A significant difference between the AD group and groups with objective and subjective memory disturbances was found for delta, theta, and alpha relative power (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996). AD group significantly lower alpha relative power in all investigated regions, in relation to the rest of the study population (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996).

Slowing on the electroencephalogram (EEG) in patients with Alzheimer's disease (AD), compared to normal control subjects, evidenced by decrease of alpha power, is a uniform finding in previous studies (Claus et al., 2000).

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**Commented [JH2]:** The predominant approach in the literature focuses on the analysis of broad frequency bands in the EEG power spectrum, from slow bands, delta (δ: 0.1–4 Hz) and theta (θ: 4–8 Hz), to faster bands, alpha (α: 8–13 Hz), beta (β: 14–30 Hz), and gamma (γ: >30–80 Hz) (Babiloni, et al., 2020).

**Perez, Duque, Hidalgo & Salvador, 2024:**  
<https://doi.org/10.1016/j.biopsycho.2024.108823>

**Commented [JH3]:** These rhythms are replaced by fast oscillations in the range of beta (14–30 Hz).

[14] Steriade M (2003) The corticothalamic system in sleep. Front Biosci 8, d878–d899.

[15] Steriade M, Contreras D, Amzica F, Timofeev I (1996) Synchronization of fast (30–40Hz) spontaneous oscillations in intrathalamic and thalamocortical networks. J Neurosci 6, 2788–2808

Babiloni et al. (2011): <https://doi.org/10.3233/JAD-2011-0051>

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**Commented [JH27]:** 29] Jeong J (2004) EEG dynamics in ...

**Commented [JH28]:** 40] Babiloni C, Binetti G, Cassetta E ...

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Compared with the normal controls, the AD patients had a significantly lower **alpha-2** band power in the resting EEG (Wada, Nanbu, Jiang, Koshino, Yamaguchi & Hashimoto, 1997).

Typical EEG changes in AD include a decrease in power and mean frequency of **alpha** activity (8–12 Hz) [21,39,71,74] (Dringenberg, 2000).

A decrease in **alpha** activity is repeatedly observed in AD (Jeong, 2004).

When compared to the resting state EEG rhythms of healthy normal elderly (Nold) subjects, AD patients showed an amplitude decrease of posterior **alpha** (8–13 Hz) source [45, 55, 56, 76–78] (Babiloni et al., 2011).

Compared with healthy older adults, patients with Alzheimer's disease (also early-onset Alzheimer's disease; Özbek, Fide & Yener, 2021) show decreased **alpha** power during resting state electroencephalography (rsEEG) (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021).

Among the most promising EEG markers are reduced **alpha** power (Cassani et al., 2017; Hatz et al., 2015; Musaeus et al., 2018) (Farina et al., 2020).

As expected, healthy ageing was associated with higher **alpha** power, both in amplitude (temporo-parietal areas) and connectivity (with frontal electrodes), which was increased in controls relative to patients, and in aMCI relative to AD (Farina et al., 2020).

For the rest with eyes-closed, it was shown that **alpha** power was reduced in MCI compared with healthy older adults (Koenig et al., 2005; Babiloni et al., 2006b, 2010; Kwak, 2006; Ya et al., 2015) (from Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021).

Findings for mild cognitive impairment (MCI), a stage of increased risk of conversion to dementia, are less conclusive (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021). Results indicate no rsEEG power differences between healthy individuals and those with MCI (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021).

No significant differences between the groups with subjective or objective memory impairment (MCI) when compared to the controls (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996).

## Theta

Increased **theta** power may have a good predictive effect on cognitive decline [11] (Liu et al., 2024). The severity of cognitive impairment is positively correlated with increased **theta**

**Commented [JH30]:** [21] Coben LA, Danziger W, Storandt M. A longitudinal EEG study of mild senile dementia of Alzheimer's type: Changes at 1 year and at 2.5 years. *Electroencephalogr Clin Neurophysiol* 1985;61:101–12.  
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[74] Pritchep LS, John ER, Ferds SH, Reisberg B, Almas M, Alper K, Cancro R. Quantitative EEG correlates of cognitive deterioration in the elderly. *Neurobiol Aging* 1994;15:85–90.

**Commented [JH31]:** [45] Dierks T, Jelic V, Pascual-Marqui RD, Wahlund L, Julin P, Linden DE, Maurer K, Winblad B, Nordberg A (2000) Spatial pattern of cerebral glucose metabolism (PET) correlates with localization of intracerebral EEG-generators in Alzheimer's disease. *Clin Neurophysiol* 111, 1817–1824.  
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[56] Babiloni C, Binetti G, Cassetta E, Cerboneschi D, Dal Forno G, Del Percio C, Ferreri F, Ferri R, Lanuzza B, Miniussi C, Moretti DV, Nobili F, Pascual-Marqui RD, Rodriguez G, Romani GL, Salinari S, Tecchio F, Vitali P, Zanetti O, Zappasodi F, Rossini PM (2004) Mapping distributed sources of cortical rhythms in mild Alzheimer's disease. A multicentric EEG study. *Neuroimage* 22, 57–67.  
[76] Ponomareva NV, Selesneva ND, Jarikov GA (2003) EEG alterations in subjects at high familial risk for Alzheimer's disease. *Neuropsychobiology* 48, 152–159.  
[77] Jeong J (2004) EEG dynamics in patients with Alzheimer's disease. *Clin Neurophysiol* 115, 1490–1505.  
[78] Pritchep LS (2005) Use of normative databases and sta...

**Commented [JH32]:** @article{babiloni2011resting, title={Resting state cortical rhythms in mild cognitive impairment and Alzheimer's disease: electroencephalographic evidence}, author={Babiloni, Claudio and Vecchio, Fabrizio and Lizio, Roberta and Ferri, Raffaele and Rodriguez, Guido and Marzano, Nicola and Frisoni, Giovanni B and Rossini, Paolo M}, journal={Journal of Alzheimer's Disease}, volume={26}, number={s3}, pages={201--214}, year={2011}, publisher={IOS Press} }

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**Commented [JH35]:** 11. Musaeus C S, Engedal K, Høgh P, et al. EEG Theta Power is an early marker of Cognitive decline in Dementia due to Alzheimer's disease [J]. *J Alzheimer's Disease: JAD*. 2018;64(4):1359–71.

activity, and an increase in **theta** waves in EEG serves as a good predictor of cognitive decline [36] Liu et al., 2024).

**data** indicate that high resting **theta** power in healthy older adults is associated with better cognitive function and may be a marker of healthy neurocognitive aging (Finnigan & Robertson, 2011).

Among the most **promising EEG markers** are increased **theta** power, as well as increased **theta** band functional connectivity (Cassani et al., 2017; Hatz et al., 2015; Musaeus et al., 2018) (Farina et al., 2020). Similar to AD models, the best features for distinguishing aMCI from healthy ageing were increased **theta power** in left temporo-parietal electrodes (Farina et al., 2020). **Theta** power was the best overall predictor of patient status, in line with the suggestion that increased **theta** is one of the first changes to occur in AD (Musaeus et al., 2018) (Farina et al., 2020).

When compared to the resting state EEG rhythms of healthy normal elderly (Nold) subjects, AD patients showed an amplitude increase of widespread **theta** source [45, 55, 56, 76–78] (Babiloni et al., 2011).

Compared with healthy older adults, patients with Alzheimer's disease (also early-onset Alzheimer's disease; Özbek, Fide & Yener, 2021) show increased **theta** power during resting state electroencephalography (rsEEG) (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021).

A significant difference between the AD group and groups with objective and subjective memory disturbances was found for **delta**, **theta**, and **alpha** relative power (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996). AD group significantly higher **theta** relative power in all investigated regions in relation to the rest of the study population (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996).

Slowing on the electroencephalogram (EEG) in patients with Alzheimer's disease (AD), compared to normal control subjects, evidenced by increase of **theta** activity decrease is a uniform finding in previous studies (Claus et al., 2000).

Compared with the normal controls, the AD patients had a significant increase in **theta** band power in the resting EEG (Wada, Nanbu, Jiang, Koshino, Yamaguchi & Hashimoto, 1997).

The AD patients showed highly significant increases in **theta** activity compared with controls (Elmståhl, Rosen & Gullberg, 1994). The topographical analysis showed a

**Commented [JH36]:** 36. Babiloni C, Visser P J, Frisoni G, et al. Cortical sources of resting EEG rhythms in mild cognitive impairment and subjective memory complaint [J]. *Neurobiol Aging*. 2010;31(10):1787–98

**Commented [JH37]:** In summary, these outcomes indicate that high resting-state **theta** power in older adults is associated with relatively greater cognitive impairment;

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**Commented [JH39]:** [45] Dierks T, Jelic V, Pascual-Marqui RD, Wahlund L, Julin P, Linden DE, Maurer K, Winblad B, Nordberg A (2000) Spatial pattern of cerebral glucose metabolism (PET) correlates with localization of intracerebral EEG-generators in Alzheimer's disease. *Clin Neurophysiol* 111, 1817-1824. [55] Mientus S, Gallinat J, Wuebben Y, Pascual-Marqui RD, Mulert C, Frick K, Dorn H, Herrmann WM, Winterer G (2002) Cortical hypoactivation during resting EEG in schizophrenics but not in depressives and schizotypal subjects as revealed by low resolution electromagnetic tomography (LORETA). *Psychiatry Res* 116, 95-111. [56] Babiloni C, Binetti G, Cassetta E, Cerboneschi D, Dal Forno G, Del Percio C, Ferreri F, Ferri R, Lanuzza B, Miniussi C, Moretti DV, Nobili F, Pascual-Marqui RD, Rodriguez G, Romani GL, Salinari S, Tecchio F, Vitali P, Zanetti O, Zappasodi F, Rossini PM (2004) Mapping distributed sources of cortical rhythms in mild Alzheimer's disease. A multicentric EEG study. *Neuroimage* 22, 57-67. [76] Ponomareva NV, Selesneva ND, Jarikov GA (2003) EEG alterations in subjects at high familial risk for Alzheimer's disease. *Neuropsychobiology* 48, 152-159. [77] Jeong J (2004) EEG dynamics in patients with Alzheimer's disease. *Clin Neurophysiol* 115, 1490-1505. [78] Prichep LS (2005) Use of normative databases and statistical methods in demonstrating clinical utility of QEEG: importance and cautions. *Clin EEG Neurosci* 36, 82-87.

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widespread increase in **theta** power over most cortical areas (Elmstahl, Rosen & Gullberg, 1994).

Typical EEG changes in AD include increased power in the **theta** (4–7 Hz) band [21,39,71,74] (Dringenberg, 2000).

An increase in **theta** activity is repeatedly observed in AD (Jeong, 2004).

Findings for mild cognitive impairment (MCI), a stage of increased risk of conversion to dementia, are less conclusive (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021). Results indicate no rsEEG power differences between healthy individuals and those with MCI (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021).

For the rest with eyes-closed, it was shown that **theta** power was either elevated or reduced in MCI compared with healthy older adults (Koenig et al., 2005; Babiloni et al., 2006b, 2010; Kwak, 2006; Ya et al., 2015) (from Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021).

No significant differences between the groups with subjective or objective memory impairment (MCI) when compared to the controls (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996).

In the MCI subjects, the EEG markers of disease progression included an increase of the power density at the **theta** rhythms in the temporal and occipital regions (Jelic et al., 2000) from Babiloni, 2015.

### Beta

As expected, healthy ageing was associated with higher **beta** power, which was increased in controls relative to patients, and in aMCI relative to AD (Farina et al., 2020).

When compared to the resting state EEG rhythms of healthy normal elderly (Nold) subjects, AD patients showed an amplitude decrease **beta** (13–30 Hz) sources [45, 55, 56, 76–78] (Babiloni et al., 2011).

Compared with healthy older adults, patients with Alzheimer's disease (also early-onset Alzheimer's disease; Özbek, Fide & Yener, 2021) show decreased **beta** power during resting state electroencephalography (rsEEG) (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021).

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[71] Penttilä M, Partanen JV, Soininen H, Riekkinen PJ. Quantitative analysis of occipital EEG in different stages of Alzheimer's disease. *Electroencephalogr Clin Neurophysiol* 1985;60:1–6.  
[74] Pritchep LS, John ER, Ferds SH, Reisberg B, Almas M, Alper K, Cancro R. Quantitative EEG correlates of cognitive deterioration in the elderly. *Neurobiol Aging* 1994;15:85–90.

**Commented [JH45]:** [45] Dierks T, Jelic V, Pascual-Marqui RD, Wahlund L, Julin P, Linden DE, Maurer K, Winblad B, Nordberg A (2000) Spatial pattern of cerebral glucose metabolism (PET) correlates with localization of intracerebral EEG-generators in Alzheimer's disease. *Clin Neurophysiol* 111, 1817–1824.  
[55] Mientus S, Gallinat J, Wuebben Y, Pascual-Marqui RD, Mulert C, Frick K, Dorn H, Herrmann WM, Winterer G (2002) Cortical hypoactivation during resting EEG in schizophrenics but not in depressives and schizotypal subjects as revealed by low resolution electromagnetic tomography (LORETA). *Psychiatry Res* 116, 95–111.  
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Slowing on the electroencephalogram (EEG) in patients with Alzheimer's disease (AD), compared to normal control subjects, evidenced by decrease of **beta** power, is a uniform finding in previous studies (Claus et al., 2000).

Compared with the normal controls, the AD patients had a significantly lower **beta** band power in the resting EEG (Wada, Nanbu, Jiang, Koshino, Yamaguchi & Hashimoto, 1997).

The AD patients showed highly significant decreases in **beta** activity compared with controls (Elmståhl, Rosen & Gullberg, 1994). The topographical analysis showed that the decrease in **beta** power was more restricted to posterior temporoparietal areas (Elmståhl, Rosen & Gullberg, 1994). The **beta** power decrease is considered to reflect cortical degenerative changes [26, 27] (Elmståhl, Rosen & Gullberg, 1994).

Typical EEG changes in AD include a loss of **beta** (13–30 Hz) activity [21,39,71,74] (Dringenberg, 2000).

A decrease in **beta** activity is repeatedly observed in AD (Jeong, 2004).

A decrease in **beta** power has been found in individuals with mild AD (Hogan, Swanwick, Kaiser, Rowan & Lawlor, 2003).

Findings for mild cognitive impairment (MCI), a stage of increased risk of conversion to dementia, are less conclusive (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021). Results indicate no rsEEG power differences between healthy individuals and those with MCI (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021). For the rest with eyes-closed, it was shown that **beta** power was reduced in MCI compared with healthy older adults (Koenig et al., 2005; Babiloni et al., 2006b, 2010; Kwak, 2006; Ya et al., 2015) (from Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021).

No significant difference was found for **beta** relative power in the **groups** studied, but a tendency towards higher values was observed in frontal regions in groups with objective memory disturbance and subjective memory complaints, as well as an increase in the left and right temporal and perieto-occipital regions in the AD group (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996). No significant differences between the groups with subjective or objective memory impairment (MCI) when compared to the controls (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996).

In the MCI subjects, the EEG markers of disease progression included a decrease of the power density at **beta** rhythms in temporal and occipital regions (Jelic et al., 2000) from Babiloni, 2015.

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**Commented [JH50]:** 26 Kcllawav P; An orderly approach to visual analysis: Parameters of the normal EEG in adults and children; in Klass DW, Daly DD (eds): Current practice of Clinical Electroencephalography. New York, Raven Press. 1979. pp 69-148.  
27 Gloor P, Ball G. Schaull N: Brain lesions that produce delta waves in the EEG. Neurology (Minnap) 1977;27:326-333

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**Commented [JH52]:** [21] Coben LA, Danziger W, Storandt M. A longitudinal EEG study of mild senile dementia of Alzheimer's type: Changes at 1 year and at 2.5 years. Electroencephalogr Clin Neurophysiol 1985;61:101–12.  
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[71] Penttilä M, Partanen JV, Soininen H, Riekkinen PJ. Quantitative analysis of occipital EEG in different stages of Alzheimer's disease. Electroencephalogr Clin Neurophysiol 1985;60:1–6.  
[74] Pritchard LS, John ER, Ferds SH, Reisberg B, Almas M, Alper K, Cancro R. Quantitative EEG correlates of cognitive deterioration in the elderly. Neurobiol Aging 1994;15:85–90.

**Commented [JH53]:** AD, MCI, healthy control



## Delta

In the morning EEG, the three groups showed differences only in the **delta** band with a prevalence of the **delta** activity in AD compared to both HC and MCI groups (D'Atri et al., 2021). On the other hand, the EEG activity of the MCI group differed from that of HC only at the frontal sites (D'Atri et al., 2021).

Prefrontal **delta** power was significantly higher in the AD compared to the HC group, while the right frontotemporal **delta** activity increased in the AD compared to both the HC and MCI groups (D'Atri et al., 2021).

When compared to the resting state EEG rhythms of healthy normal elderly (Nold) subjects, AD patients showed an amplitude increase of widespread **delta** source [45, 55, 56, 76–78] (Babiloni et al., 2011).

Compared with healthy older adults, patients with Alzheimer's disease (also early-onset Alzheimer's disease; Özbek, Fide & Yener, 2021) show increased **delta** power during resting state electroencephalography (rsEEG) (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021).

A significant difference between the AD group and groups with objective and subjective memory disturbances was found for **delta**, **theta**, and **alpha** relative power (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996). For **delta** relative power, a lower level of significance ( $p < 0.05$ ) was observed in the left and right temporal and parieto-occipital, and left frontal regions (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996).

Compared with the normal controls, the AD patients had a significant increase in **delta** band power in the resting EEG (Wada, Nanbu, Jiang, Koshino, Yamaguchi & Hashimoto, 1997). Topographic analyses of the resting EEG showed a significant increase in **delta** band power at the frontal regions/**delta** activity was observed predominantly at the frontal areas (Wada, Nanbu, Jiang, Koshino, Yamaguchi & Hashimoto, 1997).

The AD patients showed highly significant increases in **delta** activity compared with controls (Elmståhl, Rosen & Gullberg, 1994).

The topographical analysis showed a widespread increase in **delta** power over most cortical areas (Elmståhl, Rosen & Gullberg, 1994). **Delta** waves are considered to reflect primarily abnormalities of connections between subcortical and cortical areas [26, 27] (Elmståhl, Rosen & Gullberg, 1994).

Typical EEG changes in AD include increased power in the **delta** (B4 Hz) band [21,39,71,74] (Dringenberg, 2000).

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**Commented [JH57]:** @article{d2021eeg, title={EEG alterations during wake and sleep in mild cognitive impairment and Alzheimer's disease}, author={D'Atri, Aurora and Scarpelli, Serena and Gorgoni, Maurizio and Truglia, Ilaria and Lauri, Giulia and Cordone, Susanna and Ferrara, Michele and Marra, Camillo and Rossini, Paolo Maria and De Gennaro, Luigi}, journal={Iscience}, volume={24}, number={4}, year={2021}, publisher={Elsevier} }

**Commented [JH58]:** <https://doi.org/10.1016/j.isci.2021.102386>

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**Commented [JH61]:** <https://doi.org/10.3233/JAD-2011-0051>

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**Commented [JH64]:** 26 Kllawav P; An orderly approach to visual analysis: Parameters of the normal EEG in adults and children; in Klass DW, Daly DD ...

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**Commented [JH66]:** [21] Coben LA, Danziger W, Storandt M. A longitudinal EEG study of mild senile dementia of Alzheimer's type: Changes at 1 ...

An increase in **delta** activity is repeatedly observed in AD (Jeong, 2004).

Similar to AD models, the best features for distinguishing aMCI from healthy ageing were increased **delta** power in left temporo-parietal electrodes (Farina et al., 2020).

Findings for mild cognitive impairment (MCI), a stage of increased risk of conversion to dementia, are less conclusive (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021). Results indicate no rsEEG power differences between healthy individuals and those with MCI (Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021). For the rest with eyes-closed, it was shown that **delta** power was either elevated or reduced in MCI compared with healthy older adults (Koenig et al., 2005; Babiloni et al., 2006b, 2010; Kwak, 2006; Ya et al., 2015) (from Fröhlich, Kutz, Müller & Claudia Voelcker-Rehagen, 2021).

No significant differences between the groups with subjective or objective memory impairment (MCI) when compared to the controls (Jelic, Shigeta, Julin, Almkvist, Winblad & Wahlund, 1996).

In the MCI subjects, the EEG markers of disease progression included an increase of the power density at the **delta** rhythms in the temporal and occipital regions (Jelic et al., 2000) from Babiloni, 2015.

Reduced **delta** power during resting state EEG has been identified in patients with MCI (Liddell et al., 2007). Furthermore, in the study, individuals with MCI demonstrated a significant positive correlation between **delta** power and immediate memory recall. Liddell et al. (2007) proposed that these findings suggest that **delta** power may be linked to memory decline in MCI, indicating that it could serve as a sensitive indicator of prodromal or early cognitive decline. However, other studies have shown increased **delta** power in MCI patients compared to healthy controls, particularly in frontal and centroparietall regions (Adler, Bramesfeld & Jajcevic, 1999; Moretti, Zanetti, Binetti & Frisoni, 2012).