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Review

EEG frequency bands in subjective cognitive decline: A systematic review of resting state studies

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ABSTRACT

As the older population continues to expand, there is a growing prevalence of individuals who experience subjective cognitive decline (SCD), characterized by self-reported failures in cognitive function and an increased risk of cognitive impairment. Recognizing that preventive interventions are typically more effective in preclinical stages, current research endeavors to focus on identifying early biological markers of SCD using resting-state electroencephalogram (rsEEG) methods. To do so, a systematic literature review covering the past 20 years was conducted following PRISMA guidelines, in order to consolidate findings on rsEEG frequency bands in individuals with SCD. Pubmed and Web of Science databases were searched for rsEEG studies of people with SCD. Quality assessments were completed using a modified Newcastle-Ottawa scale. A total of 564 articles published from December 2003 to December 2023 were reviewed, and significant aspects of these papers were analyzed to provide a general overview of the research on this technique. After removing unrelated articles, nine articles were selected for the present study. The review emphasizes patterns in frequency band activity, revealing that individuals classified as SCD exhibited increased theta power than healthy controls, but decreased than MCI. However, findings for the alpha, delta, and beta bands were inconsistent, demonstrating variability across studies and highlighting the need for further research. Although the rsEEG of frequency bands emerges as a promising early biomarker, there is a noteworthy need to establish uniform standards and consistent measurement approaches in order to ensure the reliability and comparability of the results obtained in the research.

1. Introduction

Concerns about cognitive changes have received increasing attention due to the growing number of older individuals seeking medical assistance for these issues (Jessen et al., 2020). Subjective cognitive decline (SCD) has become particularly noteworthy because it is considered a prodromal stage of cognitive impairment (Jessen et al., 2014). A meta-analysis of longitudinal studies on SCD with a follow-up period of at least four years revealed an estimated conversion rate to Mild Cognitive Impairment (MCI) of 27 %, and 14 % to dementia (Mitchell et al., 2014).

In previous studies, various terms have been used to refer to SCD, such as subjective memory decline, subjective memory impairment, and subjective memory complaints (Ginó et al., 2010; Jeong et al., 2021). However, in 2012, researchers and clinicians in the field of Alzheimer's Disease (AD) proposed the term SCD (Jessen et al., 2014), which has been extensively accepted. SCD is characterized by two key features: (1) a self-reported decline in cognitive capacity across various cognitive domains, rather than being restricted to memory, and (2) normal performance on standardized tests used to classify MCI. Although individuals with SCD perform within normal limits on neuropsychological tests, this group is a heterogeneous population with diverse possibilities and outcomes. On the one hand, SCD has been associated with an objective cognitive performance similar to that of individuals without SCD and no progression to dementia (Sohrabi et al., 2019). On the other hand, SCD has been linked to a higher risk of objective cognitive impairment (Li et al., 2022; Numbers et al., 2023; Rivas-Fernández et al., 2023) and a reduction in functional connectivity (Yasuno et al., 2015).

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Additionally, individuals with SCD have been found to exhibit neurological changes similar to those observed in AD, including differences in both grey and white matter structures (Munro et al., 2023) and a smaller bilateral hippocampus and right amygdala compared to controls (Striepens et al., 2010). Jessen et al. (2020) also established different trajectories from SCD, such as complete remission of SCD when the underlying conditions are depression, medication side effects, or intermittent sleep disturbance. Additionally, there can be a persistent continuation of SCD due to normal aging or a progression to dementia.

Therefore, it would be beneficial to investigate early and reliable biomarkers for the detection and treatment of SCD in an attempt to maintain cognitive health and delay or prevent the progression to AD (Abdulrab & Heun, 2008). Currently, the use of electroencephalographic (EEG) measures is promising because they provide direct, non-invasive, and relatively inexpensive assessments of brain neuronal activity (Babiloni et al., 2021; Biasiucci et al., 2019). EEG measures the electrical field obtained from the summations at scalp electrodes of the oscillatory component generated by postsynaptic potentials in pyramidal cortical neurons (Babiloni et al., 2021; Biasiucci et al., 2019). Additionally, EEG offers a time resolution of ≤ 1 ms, enabling it to provide neurophysiological data that cannot be obtained from other neuroimaging techniques (Biasiucci et al., 2019).

In recent years, resting state EEG (rsEEG) measurements have emerged as a reliable tool for quantifying brain neurophysiological dysfunction. rsEEG is typically recorded from subjects during brief periods under both eyes-open and eyes-closed conditions, capturing spontaneous brain activity during periods of cognitive disengagement. This method captures neural activity independent from the cognitive task, making it resilient to factors such as fatigue, movements, anxiety, or meta-learning, as Babiloni et al. (2021) highlighted. The most common way to characterize rsEEG is by breaking down oscillatory signals into the spectral power of a frequency band. Spectral power is proportional to the rate of energy change at a specific frequency or frequency band (Ward, 2003), and it is involved in various cognitive processes. Alpha power is linked to heightened attention and task engagement, whereas theta power is associated with memory encoding and retrieval. Gamma-theta interactions may support short-term memory, and gamma oscillations are linked to processing attended stimuli (Ward, 2003). 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 H) (Babiloni, et al., 2020).

In normal aging, there may be a gradual slowing of EEG rhythms and subtle changes in neural oscillations across different frequency bands (Babiloni et al., 2006; Barry & De Blasio, 2017). However, in pathological aging, as in AD, these alterations are often more pronounced and disruptive, with significant changes in frequency bands (Lejko et al., 2020). Over the years, a substantial body of research has amassed compelling evidence pointing to a progressive alteration in brain electrical activity in neurodegenerative disorders such as MCI or AD. This alteration is characterized by an increase in theta power and a decrease in beta power, followed in subsequent stages by a decrease in alpha power and an increase in delta power (Gouw et al., 2017; Jeong et al., 2021; Prichep et al., 2006).

Although there has been extensive recent research on the use of frequency bands in individuals with SCD to investigate and understand changes in brain activity associated with early MCI and the risk of progression to neurodegenerative diseases such as AD, the findings have not yet been fully integrated. This is probably due to the heterogeneity of the methodological approaches and criteria used to characterize SCD. The current review seeks to address this gap by including studies conducted with individuals who self-report decreased cognitive abilities in different domains but demonstrate normal performance on standardized tests typically used to classify MCI. The core question guiding our research was: Are there rsEEG measures for the analysis of frequency bands that demonstrate consistent patterns in previous studies in individuals with SCD, thus providing a reliable foundation for improving early diagnosis and treatment strategies? Guided by this research question, our aim was to consolidate the findings on the spectral power of frequency bands in SCD.

2. Material and methods

2.1. Search strategy

We conducted a literature review spanning the past 20 years, following the PRISMA guidelines (Page et al., 2021). Our search, performed in December 2023 using Pubmed and Web of Science, employed a specific combination of key words. We focused on samples using terms such as “subjective cognitive decline”, “subjective memory decline”, “subjective memory impairment”, and “subjective memory complaints”. In terms of techniques, our interest encompassed “resting state EEG,” “ongoing EEG,” “background EEG,” “quantitative EEG (qEEG),” “brain rhythms,” and “brain oscillations.” We used the Boolean expression “AND” to join the two terminologies. Only studies that investigated differences in rsEEG spectral power in SCD, either exclusively or in conjunction with other EEG metrics, were included in our review.

2.2. Eligibility

The objectives of this paper and the inclusion criteria were structured based on the elements of the PICOS model (Population of interest, Interventions, Comparators, Outcomes, and Study design). Articles were selected for screening if they met the following inclusion criteria:

(1) At least one group with SCD (i.e., subjective cognitive decline experienced by the individual, but without objective cognitive impairment), including cross-sectional studies comparing individuals with SCD to healthy control or MCI groups. Additionally, we considered longitudinal studies that compared individuals with SCD who progressed to MCI with those with a stable cognitive status.
(2) Use of rsEEG to report spectral power in different frequency bands to measure the rsEEG in both conditions (eyes open/eyes closed).
(3) Articles published in English.
(4) Studies with a minimum total sample size of N = 24. Vozzi et al. (2021) proposed this threshold because, below it, results may begin to lose statistical power.

The exclusion criteria rejected studies that were:

(1) Experimental studies that lacked a comparison group, whether composed of healthy controls or individuals with MCI.
(2) Case studies, conference papers, pilot studies, and reviews.
(3) Studies exclusively focusing on other EEG metrics (e.g., asymmetry, coherence, functional connectivity, microstates, entropy, etc.).
(4) Studies employing alternative techniques, such as positron emission tomography (PET), magnetic resonance imaging (MRI), or magnetoencephalography (MEG), instead of EEG.

Manuscripts were independently evaluated in two phases. First, V.P. and A.D. independently analyzed all the titles and abstracts, considering the eligibility criteria. Second, the full texts of potentially eligible manuscripts were independently reviewed (V.P. and A.D.). Disagreements were resolved through discussion until reaching complete agreement; if agreement was not reached, a third reviewer was asked to intervene.

2.3. Data extraction

Information from each included article was independently extracted by two authors (V.P. and A.D.) and entered into tables. The extracted data included the following information: (1) authors and year of publication, (2) sample characteristics (sampling procedure, sample size, and mean age), (3) cross-sectional or longitudinal study, (4) recording conditions (eyes closed or eyes open), (5) measures of frequency bands and range, (6) spectral power type utilized, and (7) main findings.

2.4. Risk of bias assessment

The risk of bias in the included studies was assessed with a modified Newcastle-Ottawa Scale (NOS; Wells et al., 2003). This scale provides a structured framework for evaluating the methodological quality and risk of bias in observational studies. Each study was independently reviewed by two authors (V.P. and A.D.), and any discrepancies were resolved through discussion. The application of the NOS scale allowed for a systematic and objective assessment of the study quality, considering aspects such as participant selection, comparability between groups, and outcome assessment. Quality categorization was established, with scores from 7–9 denoting high quality, scores from 4–6 indicating moderate quality, and scores from 0–3 signifying low quality.

3. Results

3.1. Selection of studies

Examining the period from December 2003 to December 2023, a total of 565 publications were initially identified. After applying inclusion criteria and reviewing titles and abstracts, 400 articles were excluded, leaving 165. After removing duplicates, 30 articles remained. After a thorough review of the full-text articles, 21 were excluded for not meeting specific criteria. Finally, a total of nine articles that fully met the inclusion criteria were included in this systematic review. The selection process is illustrated in Fig. 1.

3.2. Appraisal of study quality

Regarding the quality assessment, six articles reached high quality, with each obtaining a score of eight (Jeong et al., 2021; Perez et al., 2022; Zheng et al., 2023), whereas three articles received a score of seven (Alexander et al., 2006; Prichep et al., 2006; Sibilano et al., 2023). Additionally, three articles were assessed as having moderate quality, with two earning a score of six (Gouw et al., 2017; Mazzon et al., 2018) and one receiving a rating of five (Iliadou et al., 2021).

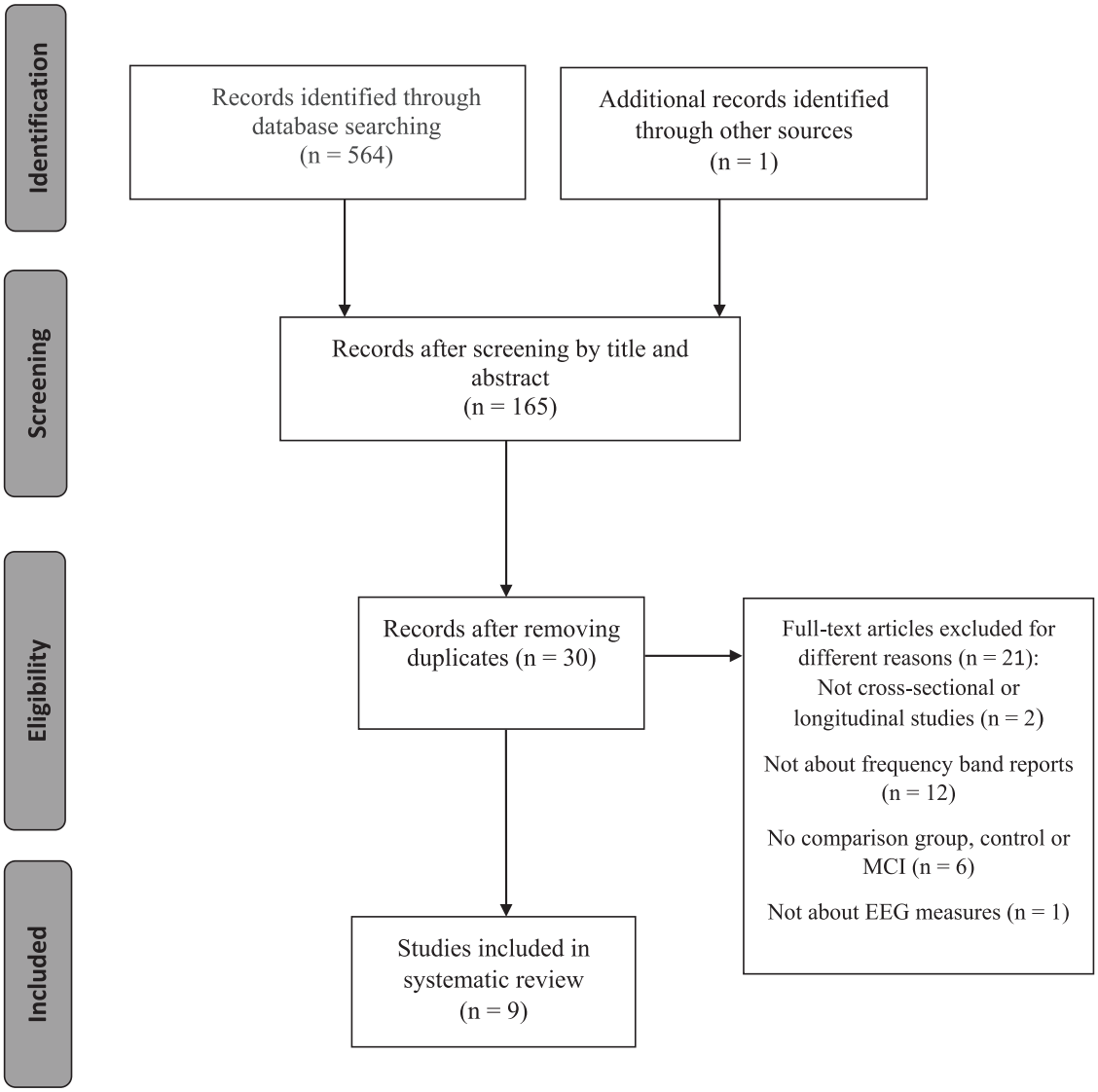

Fig. 1. PRISMA flow diagram. *Note*: MCI = mild cognitive impairment; EEG = electroencephalography.

3.3. Sample characteristics

Table 1 presents a summary of the studies and their corresponding sample characteristics. The SCD participants exhibited unimpaired cognition and were recruited through specialized memory clinics, with the exception of four studies whose samples were recruited from the community (Alexander et al., 2005; Perez et al., 2022; Prichep et al., 2006; Zheng et al., 2023). The identification of SCD varied across studies, employing diverse assessment strategies. Three of the nine studies applied questionnaires or scales (Perez et al., 2022; Prichep et al., 2006; Zheng et al., 2023), whereas one study relied on self-reporting (Mazzon et al., 2018). The SCD diagnosis in three studies was based on neuropsychological battery assessments (Alexander et al., 2006; Iliadou et al., 2021; Jeong et al., 2021). In two studies, the SCD classification adhered to criteria proposed by the Subjective Cognitive Decline Initiative (SCD-I) working group (Gouw et al., 2017; Sibilano et al., 2023).

3.4. Reporting of frequency bands during resting state

All the examined studies conducted resting-state recordings in rooms with reduced levels of light and sound. Participants were seated in comfortable chairs, and most of the studies reported providing consistent instructions to participants to remain as still as possible with their eyes open or closed, depending on the researchers' recording choice. It is worth noting that the investigations by Jeong et al. (2021), Mazzon et al. (2018), and Prichep et al. (2006) did not specify the instructions given to participants in their respective studies. In five studies, rsEEG was measured with eyes closed (Gouw et al., 2017; Mazzon et al., 2018; Prichep et al., 2006; Sibilano et al., 2023; Zheng et al., 2023). However, one study reported results for eyes open (Iliadou et al., 2021), whereas two studies reported results separately for the eyes-closed and eyes-open conditions (Alexander et al., 2006; Perez et al., 2022). In contrast, the study conducted by Jeong et al. (2021) recorded the resting state for 15 min, instructing participants to open their eyes for 30 s and close them for 30 s. Across all the reviewed studies, rsEEG activity was frequently recorded from 19 to 64 scalp electrodes placed according to the 10–20 montage system while subjects were in a state of quiet wakefulness. Only one study carried out registers using the 10–10 montage system (Sibilano et al., 2023). Frequency spectrum analysis in all the studies involved the application of Fast Fourier Transform (FFT), which assumes linearity of rsEEG signals.

Regarding frequency bands, of the nine studies, three examined the conventional five frequency bands (delta, theta, alpha, beta, and gamma). Nevertheless, in four studies, the gamma band was excluded, in three of them due to its susceptibility to muscle artifacts (Gouw et al., 2017; Perez et al., 2022; Sibilano et al., 2023), whereas Prichep et al. (2006) excluded it without providing a specific reason. One additional study split alpha and beta into sub-bands (e.g., alpha1/alpha2, beta1/-beta2), and another study went a step further by dividing beta into three sub-bands (beta1/beta2/beta3). For each frequency band, power was mostly reported in terms of relative power density, absolute power density, or spectral density. However, in the studies by Alexander et al. (2006) and Iliadou et al. (2021), the authors did not explicitly specify whether the reported power values were relative or absolute. For more details, see Table 1. Measures such as event-related potentials, connectivity, source-level, entropy, or algorithmic complexity were presented in the reviewed studies but are not included in this review.

3.5. Trends across frequency bands

Table 1 shows the dominant results for density and absolute and relative power for each band.

Four studies documented alterations in the rsEEG delta frequency band in people with SCD. Sibilano et al. (2023), Iliadou et al. (2021), and Gouw et al. (2017) conducted a thorough investigation of frequency band changes by comparing individuals with SCD to those with MCI. Additionally, Sibiliano included a group of healthy controls in their analysis. In Iliadou's study, the MCI group exhibited a significant increase in overall delta power compared to the SCD group, highlighting

Table 1
Spectral power in resting state in people with SCD.

	Sample Characteristic					
Study	Groups	Samples	Age	Design	EEG measure	Main finding
Zheng et al. (2023)	SCD, HC	N = 53	SCD (67.5), HC (66.2)	Cross-sectional	Absolute and relative powers (delta: 1-4 Hz, theta: 4-8, alpha: 8-13 Hz, beta: 13-28 Hz, gamma: 28-46 Hz)	Increased relative theta power observed in left frontal cortex of SCD group vs. HC
Sibilano et al. (2023)	SCD, MCI, HC	N = 118	SCD (66.2), MCI (74.2), HC (64.2)	Cross-sectional	Relative power (delta: 0.1-4, theta: 4-8, alpha: 8-13, beta: 13-30)	Increased delta and theta power linked to clinical progression to MCI in SCD
Perez et al. (2022)	SCD, HC	N = 146	SCD (63.8), HC (65.6), SCD young (21.3), HC young (22.8)	Cross-sectional	Density power (delta: 0.5-4, theta: 4-8, alpha: 8-12, beta: 13-30)	Increased theta power in older people with SCD vs. HC
Iliadou et al. (2021)	SCD, MCI	N = 76	SCD (65.56), MCI (66.76)	Cross-sectional	Spectral power (delta: 0.1-3 Hz, theta: 4-7 Hz, alpha: 8-12 Hz, beta: 12-30 Hz, gamma: 30-60 Hz)	Decreased delta, theta, alpha, and beta power in SCD vs. MCI
Jeong et al. (2021)	SCD, HC	N = 46	SCD (72.01), HC (72.0)	Cross-sectional	Relative power (delta: 1–3.99 Hz, theta: 4–7.99 Hz, alpha1: 8–9.99 Hz, alpha2: 10–11.99 Hz, beta1: 12–14.99 Hz, beta2: 15–19.99 Hz, beta3: 20–29.99 Hz, gamma: 30–44.99 Hz)	Increased delta power in frontal cortex; Decreased alpha1 power in occipital cortex in SCD vs. HC
Mazzon et al. (2018)	SCD, MCI, HC	N = 26	SCD (74.6), MCI (76.8), HC (74.3)	Cross-sectional	Relative power (delta: 0.5-4 Hz, theta: 4-8 Hz, alpha 1: 8-10 Hz, alpha 2: 10.5-13 Hz, beta 1:13-20 Hz, beta 2: 20-30 Hz, gamma: 30-60 Hz)	Decreased alpha2 power in left temporal, central, and parietal cortex in MCI vs. SCD; Decreased beta power in left frontal cortex in MCI vs SCD
Gouw et al. (2017)	SCD, MCI	N = 205	SCD (66.2), MCI (68.3)	Longitudinal	Relative power (delta: 0.5-4 Hz, theta: 4-8 Hz, alpha: 8-13 Hz, beta: 13-30 Hz, gamma: 30-48 Hz)	Increased delta and theta power; Decreased alpha power in MCI vs. SCD
Alexander et al. (2006)	SCD, HC	N = 158	SCD (64.9), HC (63.1)	Cross-sectional	Spectral power (delta: 1.5-3.5 Hz, theta: 4-7.5 Hz, alpha: 8-13 Hz, beta 14.5-30 Hz)	Increased frontal alpha; Increased central, parietal, and frontal beta; Increased frontal theta power in SCD vs. HC
Prichep et al. (2006)	SCD, HC	N = 44	SCD (73.5), HC (70)	Longitudinal	Absolute and relative power (delta: 1.5–3.5 Hz, theta: 3.5–7.5 Hz, alpha: 7.5–12.5 Hz, beta: 12.5–25 Hz)	Increased relative theta power in left temporal and frontal cortex; Decreased alpha power in SCD vs. HC

Note. SCD = subjective cognitive decline, HC = healthy control, MCI = mild cognitive impairment

distinctive spectral alterations. Moreover, in their spectral analysis comparing SCD and MCI, Sibilano et al. (2023) identified higher spectral power in the delta band that was associated with the clinical progression from SCD to MCI. In a longitudinal study exploring the gradual progression towards AD, Gouw et al. (2017) identified alterations in spectral power in individuals with SCD who eventually advanced to MCI. The study reported heightened delta activity throughout the cortex. Finally, Jeong et al. (2021) reported increased delta activity in the frontal cortex in individuals with SCD compared to healthy controls.

Six studies reported an abnormal rsEEG of theta power in people with SCD compared to MCI and healthy control groups. Three studies specifically explored rsEEG in individuals with SCD along the MCI continuum. Iliadou et al. (2021) observed lower spectral power in theta in SCD compared to individuals with MCI. Sibilano et al. (2023) utilized rsEEG to discriminate between SCD and MCI, identifying the delta and theta bands as discriminating the most between SCD and MCI. As mentioned earlier, the longitudinal study conducted by Gouw et al. (2017) investigated the temporal progression of individuals with SCD to MCI. They observed an increase in the spectral power of the theta band throughout the cortex in individuals with SCD who progressed to MCI. A longitudinal study by Prichep et al. (2006) also provided evidence of an increase in theta power, particularly in the right hemisphere, in individuals with SCD who experienced a decline, compared to those who remained stable. Finally, two studies reported increased theta power in individuals with SCD compared to their respective healthy control groups (Perez et al., 2022; Zheng et al., 2023). The latter analyzed absolute and relative spectral power in all frequency bands, but they only found higher relative power in the theta band in the left frontal region.

We identified six articles that reported alterations in alpha power in individuals with SCD compared to those with MCI and healthy control groups. Iliadou et al. (2021) observed a decrease in alpha spectral power in individuals with SCD compared to those with MCI. Individuals with SCD exhibited decreased alpha1, compared to the healthy control group, and increased alpha2 in the left temporal, central, and parietal cortex compared to those with MCI, as reported in the study by Mazzon et al. (2018). Additionally, a decrease in spectral power across the entire alpha band was noted in individuals with SCD who progressed to MCI in the study conducted by Gouw et al. (2017). When comparing people with SCD to the healthy control group, Jeong et al. (2021) found a decrease in alpha1, specifically in the occipital regions, whereas Prichep et al. (2006) observed a decrease in the alpha band. In contrast, Alexander et al. (2006) reported an increase, rather than a decrease, in the alpha band in individuals with SCD compared to the healthy control group.

In the case of the beta band, three studies reported noteworthy changes. Iliadou et al. (2021) observed a decrease in beta spectral power in individuals with SCD compared to those with MCI. Additionally, Mazzon et al. (2018) identified a decrease in beta power in the left frontal regions when comparing the SCD group to the MCI group. In the study by Alexander et al. (2006), which compared individuals with SCD to a healthy control group, increased beta power was observed in the central, parietal, and frontal regions in individuals with SCD.

None of the studies included in this review reported significant changes in the groups in the gamma frequency band.

Overall, individuals with SCD exhibited a pronounced increase in theta spectral power compared to healthy controls, whereas those with MCI showed a further increment compared to individuals with SCD, indicating alterations across the MCI continuum. Similar alterations across the MCI continuum were observed in alpha spectral power. Specifically, individuals with SCD displayed decreased alpha spectral power compared to healthy controls, but higher levels than in individuals with MCI. However, this trend is inconsistent because two studies reported increases, rather than decreases, in this band in both SCD and MCI. Additionally, findings for the delta and beta frequency bands are rather inconclusive, given that half of the studies did not identify significant effects within these bands. In the studies that did observe effects, an increase in delta was noted in individuals with SCD compared to healthy controls, as well as in individuals with MCI compared to individuals with SCD. The findings related to beta band activity are also unclear. Whereas one study reported an increase in beta band activity when comparing SCD and healthy controls, an examination of the MCI continuum reveals a tendency towards decreased beta band activity in individuals with MCI compared to those with SCD. Despite this overarching trend, variability in the studies' results was evident, probably stemming from variations in measurement and analysis methodologies and discrepancies in the diagnostic criteria used to define SCD.

4. Discussion

In this systematic review, our aim was to consolidate findings on the spectral power of rsEEG frequency bands in individuals with SCD. For this purpose, we compared 1) individuals with SCD and healthy controls, 2) individuals with SCD and those with MCI, and 3) individuals with SCD who progressed to MCI versus those whose cognitive status remained stable. Overall, most of the consulted studies reported an alteration in the EEG associated with SCD, as evidenced by an increase in spectral power in the low-frequency bands and a decrease in spectral power in the high-frequency bands.

However, before exploring the analysis of the frequency bands, it is essential to address how SCD were identified and defined in the consulted studies. Accurate identification of the target population is necessary for effective early diagnosis and treatment strategies for SCD. In this regard, an important challenge in SCD assessment is to adopt a unified measurement approach. It is imperative to standardize the assessment tools in order to ensure the comparability and reliability of the results across diverse studies. Since 2014 (Jessen et al., 2014), the SCD-I has sought to establish uniform criteria; however, we have observed certain heterogeneity in the measurement of SCD in the reviewed studies, as mentioned above. The SCD-I group recommends evaluating SCD measures based on factors such as the context where they are expressed, the association with a perceived decline in cognitive capacity, the onset of perceived cognitive impairment, the age at onset, the association with physical or mental conditions, medication, or substance use, and the APOE genotype. We suggest adhering to these criteria when evaluating individuals with SCD. To enhance validity, standardized methods should be validated by comparing them with objective outcome measures, including biomarker data. Given the challenges associated with the invasiveness and high costs of neuroimaging data, there is an ongoing evaluation of lower-threshold alternative techniques for brain research, with the rsEEG condition emerging as an intriguing, non-invasive, and globally accessible candidate.

Most of the analyzed studies reported abnormal rsEEG activity in individuals with SCD compared to healthy control groups. Furthermore, studies contrasting SCD and MCI reveal that rsEEG abnormalities persist and intensify as cognitive decline progresses. Our review revealed the following evidence: 1) increased delta power in individuals with SCD compared to both healthy controls and people with MCI, although these findings were not consistently reported across all the studies; 2) a progressive increase in theta frequency bands in individuals with SCD compared to healthy controls, which intensified when comparing MCI to SCD; 3) a decrease in the alpha frequency band in individuals with SCD compared to healthy controls, with this decrease being more pronounced in those diagnosed with MCI compared to SCD. However, this trend was not observed in two studies that compared individuals with SCD to healthy controls and individuals with MCI, respectively. In these studies, unexpected increases, rather than decreases, in alpha and beta frequency band spectral power were reported in the SCD groups compared to healthy controls, and in the MCI groups compared to the SCD groups; 4) a decrease in beta band activity was only noted in studies that compared MCI with SCD. Conversely, the other two studies reported increases in the frequency of this band.

What is the physiological significance of the changes observed in the spectral power of delta, theta, alpha, and beta rhythms in individuals with SCD? The alterations in the high and low components of the delta rhythms, indicative of a healthy brain, are thought to be influenced by inhibiting oscillators within the reticulo-thalamic (7–14 Hz), thalamo-cortical (1–4 Hz), and intracortical (<1 Hz) neural circuits (Steriade, 2006). Moreover, it has been proposed that thalamo-cortical circuits play a role in the generation and modulation of theta rhythms. Thus, it is plausible to hypothesize that diminished activation of neurons, possibly due to acetylcholine reduction or synaptic damage, can impact inhibitory and excitatory cortical feedback interactions that are crucial for generating cortical rsEEG rhythms. This disruption may influence the regulation of overall brain arousal, the balance of cortical inhibition/excitation, and vigilance, potentially resulting in a decrease in spectral power across the delta and theta bands. The crucial implication of cholinergic deficiency is further corroborated by EEG investigations using scopolamine, a non-selective antagonist of muscarinic receptors that hinders stimulation of postsynaptic receptors. Following scopolamine administration, healthy subjects show increased delta and theta power, along with decreased alpha and beta power (Ebert et al., 2001).

Alpha rhythms are associated with a similar mechanism within the thalamo-cortical circuitry, and they are further modulated by cortico-cortical interactions and influenced by the neurotransmitter acetylcholine (Hampel et al., 2018; Suffczynski et al., 2001). The nucleus basalis of Meynert in the basal forebrain serves as the source of cortical cholinergic innervation and undergoes significant neurodegeneration during pathological aging (Hampel et al., 2018). Consequently, alpha rhythms demonstrate a gradual decrease correlated with the deterioration of fiber tracts connecting the cholinergic basal forebrain and thalamus, thus supporting the cholinergic hypothesis (Lejko et al., 2020; Neuper et al., 2006). Further evidence for this hypothesis is found in studies that explore the use of anticholinergic medications in older adults without dementia, which has been associated with significantly slower reaction times on a measure of rapid information processing and lower scores on cognitive tests such as the Stroop test (Sittironnarit et al., 2011). Additionally, a systematic review of 27 studies conducted in older adults revealed a correlation between increased use of anticholinergic medications and reduced cognitive function (Campbell et al., 2009). Furthermore, beta rhythms may be associated with the regulation of thalamocortical flow, encompassing commands, images, and motor plans through the basal ganglia and motor thalamus (Oswal et al., 2013). As mentioned previously, Alexander et al. (2006) and Iliadou et al. (2021) found distinct alpha and beta rhythm patterns from those found in other studies reviewed. These authors suggested that the psychophysiological changes observed in the SCD in their study may reflect an initial compensatory process in response to early cognitive impairment.

In this review, studies that investigated the spectral power of frequency bands in rsEEG were included for four main reasons. First, the article focuses on these frequency bands, given the extensive literature linking their activity to cognitive processes (Başar et al., 2001). Notably, theta and gamma bands are recognized for their involvement in memory (Klimesch, 1999; Nyhus & Curran, 2010), whereas delta bands play a role in maintaining focused attention (Harmony, 2013). The alpha band has been associated with attention and memory processes (Klimesch, 1999, 2012). Although the role of beta oscillations in the cognitive process has been explored less, some evidence suggests that they are related to the state of attention (Güntekin et al., 2013). Second, rsEEG markers can easily be implemented and used independently or to support standard clinical and neuropsychological evaluations in individuals with SCD. Third, because SCD often precedes more severe conditions, such as MCI or AD, analyzing the rsEEG may be crucial in identifying early markers of changes in brain activity, making earlier interventions possible. Fourth, given that the participants are older individuals with cognitive complaints, the resting and wakefulness conditions are the most comfortable for recording because the participants are not required to perform any mental tasks, thus minimizing the influence of external factors and variabilities associated with the execution of specific cognitive tasks. However, measuring brain activity at rest has limitations. One of these limitations is continuous cognitive engagement during rest, including processes such as mind wandering and interoception. Moreover, without specific instructions, there is no control over what individuals are actually doing while they are at rest. Additionally, resting-state brain activity may not entirely reflect the cognitive and functional capacity during active situations or specific tasks. The incorporation of spectral power measures across frequency bands in rsEEG as enriching neurophysiological biomarkers in the assessment and monitoring of SCD should be based on an initial demonstration that these measures are reliable, consistent, and sensitive.

In this context, it is pertinent to highlight that the examined studies consistently reported comparable recording environments. All the studies under review indicated similar recording settings, and they were conducted in quiet rooms with low light and reduced noise levels while participants were in a comfortable position. Only three studies did not report the instructions given to the participants. In the remaining reviewed studies, the instructions for the recording were precise and consistent. Consistency in the instructions given to the participants is crucial for obtaining quality records, and evaluators must be attentive to participants' behavior during rsEEG capture to detect potential episodes of drowsiness or movement. The most commonly used resting condition was eyes closed, which tests the neurophysiological mechanisms involved in maintaining constant low vigilance with the eyes closed (for 3 to 5 min) and moderate vigilance with the eyes open (for 3 to 5 min) (Babiloni et al., 2020). However, one study reported a type of recording where subjects were instructed to open and close their eyes sequentially. This condition tests the neurophysiological mechanisms regulating the increase and decrease in vigilance. This type of recording is described in the International Pharmaco-EEG Society guidelines (Jobert et al., 2012).

In terms of electrodes, the reviewed studies reported the use of various configurations ranging from 19 to 64 electrodes. Despite the lack of a definitive consensus, it is generally considered that a minimum of sixteen channels for simultaneous recording is necessary to capture the regions responsible for generating most of the normal and abnormal EEG patterns (Sinha et al., 2016). The choice of the number of electrodes should consider practical factors such as the time required for placement and patient comfort. As mentioned earlier, this analysis aims to not only be scientifically rigorous, but also accessible and straightforward for individuals with SCD. In this context, the goal is to find an optimal balance between the complexity of electrode placement and clinical utility, ensuring that the procedure is well-tolerated by participants and can be effectively implemented in clinical and research settings.

Although the articles included in this review present promising findings, it is essential to acknowledge certain limitations identified in the analysis of frequency bands carried out in each of the reviewed investigations. Addressing these limitations is crucial for the progression of EEG research and its effective application in the study of SCD.

Although the rsEEG frequency bands are universally identified using Greek letters (e.g., delta, theta, alpha, beta, and gamma), different classifications of their frequency limits were observed in the reviewed studies. To address this lack of consensus, on the one hand, the International Pharmaco-EEG Society recommends the following frequency limits: delta (1.5-<6), theta (6-<8.5), alpha1 (8.5-<10.5), alpha2 (10.5-<12.5), beta1 (12.5-<18.5), beta2 (18.5-<21), beta3 (21.0-<30), gamma (30-<40). For gamma, they empirically choose the following ranges: gamma1 (30-<65), gamma2 (65-<90), and gamma3 (90->135) (Jobert et al., 2012). On the other hand, the International Federation of Clinical Neurophysiology (IFCN) proposes another classification, which is the one most commonly used in clinical EEG (Kane et al., 2017): delta (0.1-<4), theta (4-<8), alpha (8−13), beta (14−30), and gamma (>30–80). In understanding the distribution of electrical activity across different frequency bands, the reviewed studies have presented analyses of power density (the amount of electrical energy in a specific frequency

band per unit of frequency), absolute power (the total amount of electrical energy in a specific frequency band, disregarding other frequencies), and relative power (the proportion of power in a specific frequency band relative to the total power across all frequencies) (Babiloni et al., 2020; Singh & Krishnan, 2023). The choice of each of these measures to assess brain electrical activity depends on the objectives or the specific analyses being conducted. However, when examining the resting state, it would be advisable to employ relative power, given that it provides information about the proportional distribution of electrical activity in different frequency bands in relation to the total EEG activity. This information can yield valuable insights into potential changes in resting-state brain activity in individuals with SCD. Finally, integrating the results from different studies that use the same analytic technique into a pooled sample can significantly enhance the robustness and generalizability of the findings in the field. Therefore, we encourage researchers to consider sharing their raw data in public repositories in order to facilitate collaboration and advancement in EEG analysis.

In conclusion, this systematic review reveals a general tendency toward EEG alterations in the context of SCD. However, specific results indicate noteworthy discrepancies that highlight significant variability. This complexity underscores the need for a thorough exploration of the underlying factors that contribute to divergence in the results of frequency bands, even within the context of the overall EEG alteration observed. Despite the promising potential of analyzing resting-state frequency bands, further refinement is required for their implementation as early biomarkers of brain activity changes or as complementary information in the neuropsychological evaluation of SCD cases. Additionally, this review exclusively reports group-level differences. Further research is needed to better understand how these findings would translate into an individual diagnostic context. Adherence to the latest guidelines, such as those of the IFCN (Babiloni et al., 2020) or the American Clinical Neurophysiology Society (ACNS) (Sinha et al., 2016), is recommended for proper implementation. Constant and uniform research on these frequency bands, guided by these established protocols, can facilitate the identification of consistent patterns and provide a robust foundation for early diagnosis and the development of more effective treatment strategies. Ultimately, it is crucial to emphasize the importance of adhering to the SCD-I criteria in order to ensure the comparability and reliability of the results across various studies.

Declaration of Generative AI and AI-assisted technologies in the writing processs

The authors did not use generative AI technologies in the preparation of this paper.

CRediT authorship contribution statement

Vanesa Hidalgo: Writing – review & editing, Supervision, Conceptualization. **Alicia Salvador:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Vanesa Perez:** Writing – original draft, Methodology, Investigation, Conceptualization. **Aránzazu Duque:** Methodology, Investigation.

Declaration of Competing Interest

The authors declare no conflicts of interest.

Data Availability

No data was used for the research described in the article.

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