Title

EEG recordings as biomarkers of pain perception: where do we stand and where to go?

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Year	Study	Subjects (n)	Female	Mean age/age range	Handedness	Size of stimulation	Position of subjects	Eyes	Area of stimulation	Type of Painful stimulation	Control condition (s)	How was pain measured?	Data collected	EEG electrodes	Delta	Theta	Alpha	Beta	Gamma	Main finding
1992	Vennaas 1992	19	2	26.5	21-58	NR	R	Sealed on a mechanical eye	Closed	Masseter muscle	(1)Baseline and (2) Imagined pain	The subject was given a thumb switch to indicate his/her present pain intensity	Data collected The recorded EEGs were visually inspected, and epochs containing no visible artifacts were manually selected. Artifacts from physiologic sources such as muscle activity from swallowing, eye movement and blood from non-physiologic sources (e.g., movement of electrodes) were rejected. The EEG was digitized at a sampling rate of 256 samples/sec every four seconds, however, the by 2.5 sec artifact free epochs were chosen for analysis. In experimental pain, such sampling was performed for the conditions of pain with an intensity of greater than 5 on the 10 point intensity scale. Each selected epoch was subjected to Fast Fourier Transformation (FFT). The following frequency bands were used for the analysis of the EEG: delta (0.5-3.5 Hz), theta (frequency bands (delta: 0.5-3.5 Hz, theta,alpha: 3.5-12 Hz, beta: 13-30 Hz, and the frequency range of 35-100 Hz) of specified cortical areas, and the total power of all frequency bands combined (0.5-100 Hz). The frequency band of 35-100 Hz was included to investigate whether the effects to pain were limited to the beta frequencies, or alternatively, whether other frequency band would show similar effects. No attempt has been made further to remove the common EEG frequency bands, e.g., alpha activity and harmonics of the delta frequency band.	8	NR	NR	NR	Increased at the temporal recording sites.	NR	Compared to baseline, spectral analysis of EEG measures during experimental pain demonstrated statistically significant increases in the beta and 35-100 Hz frequency ranges, most notably at the temporal recording sites.
1996	Persson 1996	15	0	NR	23-51	R	Both	Sealed on an upright chair	Closed	Hand	Baseline	At the end of each immersion the subject quantified the pain sensation by means of a Visual Analogue Scale (VAS)	As the beginning of each session, at least 3 min of baseline artifact free EEG was recorded. EEG signals were amplified, filtered (0.16 Hz, 3.4kHz), A/D converted (128 samples/sec, 12 bit), divided into 2 sec epochs, and stored for off-line analysis. Raw EEG signals were visually inspected and artifacts were rejected. The EEG was digitized for further processed. By means of a 1024 point Fast Fourier Transform, the absolute and relative power spectra were calculated for the frequency bands delta (2-4 Hz), theta (6-8 Hz), alpha (8-12 Hz), alpha (10-12 Hz), beta (12-16 Hz), and beta (16-30 Hz). To eliminate any possible contamination by artifacts not detected by visual analysis of the EEG, we consider not to analyze epochs containing artifacts. Artifacts were excluded from the analysis because of possible electromyographic contamination.	8	Delta activity increased. The increase in delta power at Fz at a trend level.	Theta activity increased.	Alpha-2 power changes were lateralized. During the lateralized beam analysis,	Beta	NR	During pain perception almost no coherence changes in the theta band were observed, but great increases in coherence in the alpha band between central, parietal and frontal electrodes. The network of coherence changes in the alpha band showed a strong involvement of the central-C3 connecting coherence increases with frontal-F3 and parietal-P3 and a coherence increase within the left hemisphere was much pronounced during pain.
1998	Chen 1998	10	0	27.6	22-68	NR	R	Sealed	Open	Hand	(1)Baseline and (2) Non-painful cold	Immediately at the end of cold pressor test, subjects rated their pain sensation in a graded verbal rating scale for intensity	The EEG was digitized with 128/sec and sensitivity set to 10 for processing. Corneo-retinal potentials were used to detect and reject artifacts. Artifacts were also rejected if the amplitude exceeded 100 μV. Artifact free 2 epochs were chosen for further processing. Dependent on the artifact rejections, in total 80 to 160 epochs (average 120 ± 16, median 122) for the resting condition, 20 to 100 (average 65 ± 22, median 60) for the cold conditions, and 9 to 61 (average 36 ± 18, median 32) for the pain condition were used. Fast Fourier Transform (FFT) was performed on the artifact free epochs to obtain power spectra with a frequency resolution of 0.5 Hz. Relative power spectra and 17 2 cross-power spectra between all possible electrode pairs were calculated for each record. Data reduction of the spectra was performed by averaging adjacent spectral lines to obtain broad band power: two for four frequency bands: Delta (0.5-3.5 Hz), Theta (6.0-7.5 Hz), Alpha (8.0-12.5 Hz), Beta (13.0-30.0 Hz). Coherence was calculated from the amplitude and coherence per frequency band. In total 7776 (9 amplitudes and 4*17*1-68 coherences) values were obtained for each record and stored in a database	19	Increased power at the vertex of cold pressor test, subjects rated their pain sensation in a graded verbal rating scale for intensity	The coherence network exhibited only enhancement mainly between frontal and central electrodes in the left hemisphere. The increase in coherence between the left prefrontal electrode Fp1 and left temporal and posterior sites	No coherence change was observed in the theta range.	The coherence network exhibited only enhancement mainly between frontal and central electrodes in the left hemisphere. The increase in coherence between the left prefrontal electrode Fp1 and left temporal and posterior sites (T3, P3, O1).	In the upper frequency beta-1 EEG, the coherence network pattern showed much difference between the left hemisphere with many increased coherence and the right hemisphere with a number of coherence decreases. Enhanced coherence between the left prefrontal electrode Fp1 and sites in the right hemisphere between electrode T6 and contralateral electrodes only coherence decrease was found. Amplitude increase in T5 was accompanied by coherence increase whereas amplitude increase in Fz was accompanied by coherence decrease. This indicates clearly that amplitude and coherence are different measures.	NR	During pain perception almost no coherence changes in the theta band were observed, but great increases in coherence in the alpha band between central, parietal and frontal electrodes. The network of coherence changes in the alpha band showed a strong involvement of the central-C3 connecting coherence increases with frontal-F3 and parietal-P3 and a coherence increase within the left hemisphere was much pronounced during pain.
2000	Le Pera 2000	12	0	26.6	NR	NR	L	Sealed on a mechanical eye	Closed	Brachioradialis muscle	(1)Baseline and (2) Vibration	The subjects rate a 0-10 electronic visual analogue scale (VAS) continuously throughout the pain intensity where 0 an indicated "no pain" and 10 an "intolerable pain". The VAS scores were sampled every 5 s by the computer. The pain rating during the recording of EEG in a time interval of 60 s was calculated	Fz, Cz, Pz, C3, C4, T3, T4, T5, T6, O1, O2	Significant increase of power within delta band over the right posterior parietal lobe (P6)	NR			Significant increase of power within beta 2 band over NR		Increments of both delta and alpha 1 powers were observed during painful stimulation of the arm, more pronounced over the region contralateral to the painful stimulation.
2001	Chang 2001	15	0	25.6	22-28	R	L	NR	Open	Brachioradialis muscle	(1)Baseline and (2) Isotonic saline injection	Intramuscular injection of capsaicin (50 μg/0.5 ml) 6cm below the elbow	The general EEG signals were amplified (10,000 times), filtered (0.16 Hz-3.4 kHz), digitized (128 samples/sec, 12 bit), and stored for off-line analysis. Raw EEG signals were visually inspected and artifacts were rejected. The EEG was digitized for further processed. By means of a 1024 point Fast Fourier Transform, the absolute and relative power spectra were calculated for the frequency bands delta (2-4 Hz), theta (6-8 Hz), alpha (8-12 Hz), alpha (10-12 Hz), beta (12-16 Hz), and beta (16-30 Hz). To eliminate any possible contamination by artifacts not detected by visual analysis of the EEG, we consider not to analyze epochs containing artifacts. Artifacts were excluded from the analysis because of possible electromyographic contamination.	11	Increased delta power at the vertex of frontal region and frontal-central area with a right predominance	Decrease in theta power spectrum over the central region	Decreases in alpha-1 and alpha-2 powers in the posterior areas in beta-1 and beta-2 powers at the periphery	NR		Increase in beta-2 activity during muscle pain was significant over the anterior areas of the frontal	
2002	Bokhari 2002	12	NR	NR	NR	NR	L	NR	Open	Medial nerve at the wrist	(1)Non-painful electrical stimulation	Electrical stimulation at 3Hz	The stimulation levels were determined by a series of increasing and decreasing stimulation intensities. A homogenous set of stimulation blocks, consisting of the stimuli was rated verbally by the subjects on an numerical scale ranging from 0 (no sensation) to 10 (pain tolerance threshold). In this scale, values of 2 are pain, thumb mouth (rate) and 8 (slight pain) indicated the motor and pain thresholds, respectively. Furthermore, value of 9 (moderate pain) corresponded to a pain level proportionally divide -ated between values of 5 and 10.	31	NR	Increase in theta at FC2	Increase in alpha at FC2	Increase in beta1 at C3 (contralateral to pain); decrease increase in gamma at C3		Compared to nociceptive stimulation, painful electrical stimulation of the median nerve produced decrease of the power locked beta band response in the ipsilateral frontal-central area.
2002	Chang 2002	15	0	26.4	22-26	R	L	Supine	Both eyes open and closed epochs	Hand	Baseline	The subjects were requested to verbally report pain rating scales per 15 s, and the rating scales were recorded by experimenters.	Each valid epoch (2024 ms) of the EEG data (after 50 ms time-delay) and artifacts rejection) was subjected to Fast Fourier Transformation (FFT) to obtain the EEG power in each band and the absolute EEG power (summed pSD) in each broad band of every electrode where the EEG was recorded. The relative power spectrum was computed to identify the differences in the shape of EEG activation. The statistical correlation across the experimental stages and spatial correlation between the electrodes were analyzed in respect of the sources of the EEG activation.	32	Activity increased in the fore frontal areas and central-medial frontal area	No significant changes.	The alpha-1 and alpha-2 activities decreased in the pre The beta-2 activities increased bilaterally in fronto-temporal	NR		The increase of low frequency EEG activities in the frontal part and decrease in activation of EEG activities in the high frequency range in temporal sites could be interpreted as hypnosis. Loss of sensation of regulation (or habituation) and the stress of pain. The frontal-central-temporal-parietal-occipital cluster is independent from the posterior-parietal alpha activation cluster, which may reflect the central processed sensational effect vs. attention processing of nociceptive input, respectively.
2003	Chang 2003	13	0	25.9	NR	R	L	Sealed	Open	Brachioradialis muscle	Baseline	Intramuscular injection of hypertonic (5.8%) saline	EEG activities were continuously recorded 1 min before the first injection as baseline, and during the entire course of each trial of pain experience (0.01-0). If the injection of isotonic saline did not induce pain (100-0), the EEG recording was conducted for 2 min immediately after the initiation of injection. Continuous EEG data were digitized (256 Hz/12 bit) and processed by linear detrending and ocular artifact reduction, using the Brain program Neuroscan 1.1. Conspicuous artifacts were rejected by visual inspection epoch by epoch. For each channel, the relative (percentage of total EEG power) and absolute EEG power spectra in frequency (0-45 Hz) domain were calculated by averaging the epochs after fast Fourier transform (FFT) with a Hanning window. The EEG spectrum was divided into the following divisions of frequency (band): Delta (0.5-4 Hz), theta1 (4.5-6 Hz), theta2 (6.5-8 Hz), alpha1 (8.5-10.5 Hz), alpha2 (11-13.5 Hz), beta1 (14.0-21.0 Hz), and beta2 (21-35 Hz). General EEG topographic patterns, global relative (percentage of total EEG power in the six bands) in the above bands were obtained	31	No significant differences in the EEG changes of delta activity were found between repeated muscle pain and control.	No significant differences in the EEG changes of theta.	Global alpha-1 and alpha-2 activity (%) significantly decreased	Global beta activity significantly increased during the first	NR		Global relative EEG power were significantly changed throughout her pain trials, and EEG power (absolute) peaked from all the electrodes were significantly increased during the painful muscle stimulation. Global EEG power (absolute) in alpha-1 band was negatively correlated to the pain intensity. The total EEG power in beta-2 band positively correlated to pain intensity.
2006	Huber 2006	20	0	26.9	20-52	R	L	Sealed on an upright chair	Closed	Volar forearm	(1)Baseline and (2) Non-painful heat. Three levels of attention were always: mind-wandering, attention-demand, and no control of attention	Tonic heat stimulus consisting of a series of small heat pulses with a constant frequency of 0.5 pulses/sec and an equal duration (1.4°C, in the experimental blocks with tonic painful heat the pulse were tailored to have a peak temperature of 7°C above the individual pain threshold)	Before the experiment started the pain threshold had been determined Subjects were asked to verbally rate the level of perceived pain on a 0-100 numerical rating scale (NRS) ranging from "no pain" (0) to "the most intense imaginable pain." Four NRS were obtained in total: through out the experiment, of which three were obtained during the application of the five minute long tonic stimuli, both innocuous and noxious, namely one after each (third 100 s). A fourth overall NRS was collected up to 10 s after the tonic stimulus. The instructions were: "Please, rate the intensity of the stimulation." "Please, NRS: please rate: what the overall pain you have experienced during the stimulus?"	The subjects rated intensity and unpleasantness of sensation during the last 10 s of each minute. The rating interval was always signalled by an audio cue	Activity increased in the fore frontal areas and central medial frontal area	No significant changes.	The factor "stimulation" produced significant effects for power density in the delta2 frequency band. Post-hoc comparisons showed a significant increase of power density in the delta2 frequency band in the two frontal EEG derivations, when comparing each of the two conditions with tonic stimulation was compared separately to baseline. However, the significance of differences was completely lost when the condition with tonic painful heat was compared to the condition with tonic non-painful heat.	Theta changes were obvious only in the two frontal EEG derivations, where a trend of left temporal (T5) increase in power NR			Wavelet (1) during tonic thermal stimulation a pattern of EEG responses characterized by a rather generalized increased delta2 activity, a left biased increase in theta2 activity and a right biased decrease in the alpha2 activity and a left biased temporal increase in the beta2 activity but we found (2) no evidence that these changes are specific to tonic heat pain and not for the changes in attention, or in the expectation of painful stimulation. The EEG patterns were also affected by our attentional manipulations, with attention focused on pain and on the painful stimulation, which proved to be effective as regards the subjective experience of pain, but not as regards the EEG patterns, suggesting a marked stability of brain activity while processing tonic thermal stimulation. Subjects with low cognitive distraction showed a significant positive relationship between alpha2 (PO2) EEG activity and average subject pain ratings.
2009	Sjogaard 2009	40	20	NR	19-50	R	R	Sealed	Both eyes open and closed at baseline, eyes closed during pain	Upper arm	Baseline	Before the experiment started the pain threshold had been determined	The EEG data was digitized at 256 Hz and stored for off-line analysis. Raw EEG signals were visually inspected and artifacts were rejected. The EEG was digitized for further processed. By means of a 1024 point Fast Fourier Transform in order to produce the power density in the alpha2 (7.5-9.5 Hz) and alpha1 (10-12 Hz) bands. All artifact free, one second segments were selected for further analysis on each subject. After decomposing into 256 Hz, power spectral density were computed by averaging the FFT of the 256 sample points. Power spectral density was computed for the entire duration of all artifact free stimulation conditions (baseline, innocuous stimulation, noxious stimulation). Spectral windows were shifted in 0.125 s overlapping intervals. The analyzed alpha band frequencies were defined as 7.5-12.5 Hz. Authors calculated the general power of each each alpha band per individual, using the individual alpha peak frequency. The individual alpha peak frequency was defined as the frequency of the alpha band and the band width was determined by the range between the 1st and the higher bound of the alpha band to alpha2.	124	NR	NR	Decreases in alpha2 (PO2), alpha1 (PO2), alpha2 (PO7) NR	NR		
2012	Nir 2012	18	9	26	NR	R	L	Sealed on an upright chair	Closed	Volar forearm	(1)Innocuous stimulation	Heat stimulation (50 °C, 30 s) and cold stimulation (0 °C, 30 s) were applied to the volar forearm of healthy subjects. Subjects were requested to rate the intensity of the thermal stimulation on a 0-100 numerical pain scale during a 50 s stimulus	Spectral analysis of EEG amplitude was carried out. To assess the data EEG spectral power, we used a fast Fourier transform (FFT) with a Hanning window to calculate the power in the following frequency bands: theta (4-7 Hz), alpha (8-13 Hz), alpha1 (10-12 Hz), beta1 (12-18 Hz), beta2 (18-30 Hz), beta3 (30-42 Hz) and gamma (42-70 Hz). The wavelet coefficients were averaged over time and these scales contained within frequency band were summed together to yield the absolute activity within each frequency band.	32	NR	NR	Power values of both alpha-1 and alpha-2 sub-bands NR	NR		In the noxious conditions, alpha-1 power obtained at the beginning of the pain was negatively correlated with pain intensity. Additionally, resting alpha-1 power was negatively correlated with the temporal summation, and resting alpha-2 pain intensity reported during the noxious condition
2015	Gram 2015	39	18	26.9	NR	NR	L	NR	Open	Hand	Baseline	The subjects immersed their left hand up to the wrist for 2 min in circulated water at 2C	Subjects rated their perceived pain on a handheld electronic device with a visual analogue scale (VAS) ranging from no feeling of pain to the worst imaginable pain. The pain ratings were continuously sampled electronically with a frequency of 10 Hz on a scale from 0 to 10.	62	During the CP condition delta increased during CP. Relative power also increased	During the CP condition theta decreased during CP.	During the CP condition alpha1 and alpha2 decreased During the CP condition beta1 increased during CP. During the CP condition gamma increased during CP and in the recording relationship to pain perception.			Theta, beta1 and gamma bands were correlated to the ever-under course of pain ratings. No dynamics in beta1 and gamma EEG bands, indicating that these bands are not sensitive to the temporal sequence of noxious stimuli. Interestingly, however, dynamics in the theta range were clearly correlated to pain ratings, underlining a strong inter-individual relationship to pain perception.
2015	Schulz 2015	61	22	26	NR	NR	L	NR	Open	Dorsum of the hand	Tonic heat stimulus	Continuous pain rating on a visual analogue scale (VAS) ranging from 0 to 100 and anchored at no pain and most intense pain using a custom built finger-span device implemented as a joystick-controller controlled by their right hand.	Tonic-frequency analysis were performed. Average power was computed for each time point in the following frequency bands: theta (4-7 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-100 Hz). In the tonic pain condition, the initial increase and the final decrease of stimulus and pain in tonicity were discarded resulting in an 8 min analysis window	61	NR	Positive relationships for pain intensity in brain activity	Negative relationships for pain intensity in alpha activity	Negative relationships for pain intensity in beta activity	Bilateral gamma oscillations at frontal electrodes were	Subject to pain intensity was specifically encoded by gamma oscillations recorded over medial-frontal electrodes, whereas subject to stimulus intensity was negatively related to beta oscillations lateralized to the hemisphere contralateral to
2015	Rouhana 2015	25	13	23.8	NR	NR	R	NR	NR	Sural nerve over its retromalleolar path.	(1)Innocuous stimulation	The subjects were requested to verbally report pain on a 0-100 numerical pain scale	Tonic-frequency analysis were performed Time-frequency information was obtained using the gamma-gram function in MATLAB to capture the temporal changes in power in each of the following frequency bands: delta (1-3 Hz), theta (4-7 Hz), alpha (8-13 Hz), beta (13-30 Hz), low gamma (30-45 Hz) and total (1-120 Hz). Two different calculations of power change were performed in the study to quantify the power spectral changes in the EEG data and (ocular corrected). The first type of power change was based on the EEG sensor data and it was calculated from all recorded EEG channels. The second type of power change was calculated using the EEG sensor data projected onto the brain sources. Independent component analysis (ICA), dipole fitting and cortical source mapping (Brain Storm) were used to localize the sources. Frontal, left parietal, and occipital regions (illustrated in Fig. 3B). Frontal electrodes included F1, FFz, FF1, FF2, AF1, AFz, AF2, F5, F6, FC5, FC6, FC1, FC2, FC4 electrodes include C5, C3, C1, CP5, CP3, CP1, P5, P3, P1, right electrodes include C6, C4, C2, CP6, CP4, CP2, P6, P4, P2, and occipital electrodes include PO7, PO3, PO1, POz, PO2, PO4, PO8, O1, OZ, O2.	32	Increased delta activity frontal and less in posterior leads.	Increased theta activity frontal and less in posterior leads	NR	NR		Increased theta activity within the right middle frontal gyrus predicted increased sensitivity of pain as stimulation is repeated within the pain block
2016	Zhang 2016	21	7	21	NR	Same L and same R	Both sides	NR	Dorsum of hand	Heat stimuli is where the temperature of the thermode was increased to a predetermined level (40-47C) and kept for 30 s	Non-painful heat	The stimulus intensity applied was kept within each subject's individual tolerance range. The stimulation was applied to the dorsum of the hand and each stimulus was repeated 10 times. Depending on the individual tolerance, the stimulation temperature for each subject varied but the temperature stayed within the overall range of 40C to 47C. For example, if a subject reported at 41C, the pain was at 3 or 4 out of 10, the highest temperature at the person received was 47C. If the subject reported that 45C was extremely painful, 45C would be the highest temperature the person received.	61	Agglomeratively normalization was observed. There was a local increase in alpha power in the frontal area, however, when compared over all electrodes, the changes are negative. The reduction in alpha power was mainly concentrated in the contralateral somatosensory area near electrode C4.	Agglomeratively normalization was observed. No significant changes.	Agglomeratively normalization was observed. No significant changes.	No significant changes.	No significant changes.	The observed systematic effects that distinguish the painful from the non-painful trials must originate from spontaneous intracranial fluctuations of the brain activity. Alpha and beta bands in the frontal and parietal lobes showed a decrease in power during the painful stimulus period in cases where the stimulus was rated as painful, compared with those cases when the stimulus was perceived as non-painful. Alpha and beta bands showed a decrease in power consistent to subsequent sensory pre-cursing and stimulus specific to pain.
2016	Tander 2016	20	9	26.9	NR	R	L	Sealed	Open	Hand	Electrical stimulation with a pulse length fixed at 2 ms and a current that was adjusted manually by the experimenter	(1)Non-painful electrical stimulation	The first block of EEG trials was used to determine the 50% pain threshold.	For each subject and each condition, EEG epochs were transformed to the frequency domain using a discrete Fourier transform. Inspected amplitude spectra (AS) ranging from 1 to 100Hz. Amplitudes of EEG oscillations in theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-90 Hz) bands were calculated for each condition and electrode. The obtained single-epoch amplitude spectra for each condition and electrode were averaged across epochs to enhance the signal to noise ratio	64	NR	For theta band, the spatial power decreased slope NR	NR		The relative power increase in gamma band after stimulation is in pain.
2016	Li 2016	45	0	22	NR	R	L	NR	NR	Masseter muscle	(1)Baseline and (2) Isotonic saline injection To control for the sensory, motor and attentional components of the continuous pain rating procedure, authors performed two visual control conditions. In these two conditions, the temporally inverted time-reversed pain stimuli were used to have pain right-skewed time-reversed presentation changes of the length of the vertical red bar over time. Subjects were instructed to continuously follow the length of the red bar using the finger-span device	Intramuscular injection of hypertonic saline (5% NaCl 0cc/kc, followed by a subsequent continuous infusion at variable speed	Real time feedback of ratings to ensure perceived pain intensity maintained at an approximate preset NRS level.	64	No significant differences of spectra were observed	No significant differences of spectra were observed	No significant differences of spectra were observed	Significant differences of spectra were decreased by subjects rated in a trial of vertical regions		Positive relationship between the amplitude of gamma oscillations and pain intensity ratings.
2017	Nickel 2017	39	18	26.3	NR	R	Both sides	NR	Dorsum of the hand	Heat stimuli	Non-painful heat	Subjects were instructed to continuously rate the perceived pain intensity on a visual analogue scale (VAS) ranging from 0 to 100 anchored at no pain and most intolerable pain using a custom-built finger-span device controlled by their right hand.	EEG data were band pass filtered in theta (4-7 Hz), alpha (8-13 Hz), beta (14-29 Hz) and gamma (30-100 Hz) frequency ranges, using finite impulse response filters with zero-phase shift (forward and backward). The raw EEG frequency-specific brain activity were computed in source space. The Hilbert transform was applied and absolute values of the Hilbert transform, i.e. the amplitude within the respective frequency band, were computed.	61	NR	No significant differences were observed	Increasing stimulus intensity was associated with decreasing stimulus intensity was associated with decreasing stimulus intensity was.				EEG data showed that stimulus intensity was modulated by decreases of neuronal oscillations in alpha and beta frequencies in sensorimotor areas. In contrast, pain intensity was modulated by gamma oscillations in the medial prefrontal cortex. Stimulus intensity and pain intensity were correlated simultaneously to ongoing of alpha oscillations in contralateral sensorimotor areas depended on the stimulus intensity. In contrast, a comparison analysis of right and left hand stimulation revealed that the encoding of pain in the medial prefrontal cortex was independent of the site of stimulation.
2017	Martel 2017	19	12	29	NR	R	L	NR	NR	Volar forearm (middle)	1% capsaicin cream	Baseline	Capsaicin-induced pain was modulated by the participants using a visual analogue scale (VAS, 0 = "no pain", 10 = "the most imaginable pain"), every 5 min until the pain sensation stabilized. In addition, participants rated same intensity of pain in 2 consecutive VAS pain ratings. Once the pain became stable, EEG was recorded.	For each participant, 10 non-overlapping, 2-segments will be cut at fifteen seconds randomly selected and decomposed in eight frequency bands: δ (delta: 1.5-4 Hz), θ (theta: 4-8 Hz), α1 (alpha 1: 8-10 Hz), α2 (alpha 2: 10-13 Hz), β1 (beta 1: 13-21 Hz), β2 (beta 2: 21-30 Hz), β3 (beta 3: 30-40 Hz) and γ (gamma:40-70 Hz). For each segment, intracranial source current densities were then computed. Spectral analysis was performed using Fast Fourier Transform. Relative power spectra were calculated for each electrode for the frequency bands delta (0.1-4 Hz), theta (4-7 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-100 Hz). The relative power of all 20 epochs per stimulus intensity were averaged to obtain a single power value for each stimulus intensity, separately for each frequency band and electrode	32	NR	Significant increase in brain activity across the left dorsolateral prefrontal cortex	Significant increase in brain activity across the left dorsolateral prefrontal cortex	Significant increase in brain activity across the left cortex	NR		Compared to baseline, resting stabilization activity significantly increased after capsaicin application in the left dorsolateral prefrontal cortex (alpha frequency), and left sensorimotor cortex (beta1 frequency). A pain-evoked increase in the right primary motor cortex (MC) activity was also observed (beta frequency). Pain-evoked brain activity in the cortex showed a reduction in cortical spatial extent (depicted by TMS neuronavigation). These participants further showed greater beta MC-cortex connectivity than the other participants.
2018	Bunk 2018	96	18	22.6	NR	NR	L	Sealed	NR	Dorsal thigh (leg)	Heat stimuli	Non-painful heat	Subjects rate sensation ratings were assessed at the end of every minute	11	No correlation with pain sensation	Increased pain sensation being related to a decrease in increased pain sensation being related to a decrease in subjective pain sensation is significantly related to	NR			Subjective pain sensations could significantly predict differences in EEG activity in several frequency bands. Increased pain sensation being related to a decrease in pain sensation was associated with a decrease in alpha1, beta1, beta2 as well as in theta activity across the medial-occipital sites.