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Modulation of Occipital Alpha Rhythm in Expert and Novice Surgeons Performing Suture

Sergio Reyes; Matías Quiñones; Johanna Kreither; Javier López-Calderón; María de la Luz Aylwin*

[1]School of Medicine, Talca University, Av. Lircay s/n, Talca, Chile

[2]Medical Research Center, School of Medicine, Talca University Av. Lircay s/n, Talca, Chile

[3]Associate Research Program (ARP) in Cognitive Sciences, Center for Research in Cognitive Sciences, Faculty of Psychology University of Talca Av. Lircay s/n, Talca, Chile.

Abstract

Background: Surgeons learn to perform highly repetitive suture movements. Simple movements elicit synchronization of the alpha frequency band (8–12 Hz) in occipital area, attributed to inhibition of task irrelevant areas. Yet, there is limited evidence on alpha amplitude in complex motor performance. In this study, we evaluated the impact of movement performance, expertise and task demand in the alpha power in occipital areas during suturing.

Methods: We obtained the EEG alpha power spectra and the number of sutures in expert surgeons and medical students while performing six trials, five min each, of continuous open suture: three self-paced and three fast-paced, and one three min trial in resting, eyes open, condition.

Results: Expert surgeons performed twice the sutures than medical students and further increased performance by 20% with greater task demand. Alpha power in occipital areas increased during movement execution in surgeons and medical students relative to resting, yet mean alpha was not additionally modulated by expertise or task demand. Interestingly, expert surgeons had a positive correlation of alpha power and suture performance.

Conclusions: Continuous complex movements associate with EEG alpha power in occipital areas, consistent with the inhibitory-attentional hypothesis of alpha rhythm suggesting a redistribution of the attentional resources away from the occipital areas. In contrast, expertise and task demand do not further shape alpha power. Finally, the linear correlation of alpha power with motor performance in surgeons suggests that expert's greater movement efficiency associates with further redistribution of attentional resources away from occipital areas.

Keywords: Alpha power; EEG; Open Suture; Expertise; Task demand.

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Correspondance: *María de la Luz Aylwin, Center for Medical Research, School of Medicine Associate Research Program (PIA) in Cognitive Sciences, Research Center in Cognitive Sciences, Faculty of Psychology University of Talca Av. Lircay s/n, Talca, Chile.*

Tel: 567-1220-2887; Email: maaylwin@utalca.cl

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Introduction

Surgeons learn to perform complex manual skills through systematic practice [1-3]. Skillful performance is characterized by increased movement speed and accuracy of [4-6], likely involving the transition from goal- to habit-directed behavioral control and the development of movement automation [7,8].

In humans, brain activity during complex movements has been assessed primarily by EEG recordings of simple self-paced movements and visually- and auditory-triggered movements. Simple voluntary movements modulate the alpha rhythm (8-12 Hz) in the visual and somatosensory-motor areas. Specifically, hand movements cause an alpha decrease or desynchronization, also known as mu rythm, in the hand areas and a synchronization in the foot areas [9,10]. The degree of synchronization also varies with the phase of movement, showing a decrease prior to movement followed by an increase during movement [9,11,12]. These results show an alpha modulation in the somatosensory-motor cortices in opposite directions in different phases of movement, which should result in little or no modulation of mean alpha amplitude for continuous movements. Conversely, hand and foot voluntary movements increase alpha amplitude over posterior electrodes [11,12] resulting in a synchronization of the alpha band during movement execution [13] and movement observation [14]. Summarizing, alpha amplitude in the occipital electrodes increases during the execution of continuous movements.

The two main hypothesis about the mechanism of the alpha rhythm are the absence of sensory input and the inhibition of task-irrelevant networks. The first named the 'idle rhythm hypothesis' [15] posits that alpha synchronization is a consequence of a reduced bottom-up sensory input [9,15]. The second hypothesis posits that alpha synchronization is a consequence of a bottom-down inhibition of task irrelevant areas [16-18], together with a redirection of the processing resources towards areas relevant to the task [19]. In addition, alpha oscillations have been associated with the selection of attended objects and the inhibition of non-attended distractors [20], in the visual and tactile modalities. A decrease in alpha has been observed over parieto-occipital areas cotralateral to the attended visual hemifield [21,22] and an increase over the occipital areas contralateral to the ignored stimuli [22] for visual stimuli. Similarly, there is an increase in occipital alpha amplitude correlated with performance at the posterior electrodes [23], indicating a general modulation in a tactile task. For the alpha inhibition theory, optimal performance on a task should correlate with an increase in alpha amplitude in areas where attentional resources are not needed to perform the task [20]. Thus, alpha oscillations in the occipital area for a complex visuo-sensorimotor task are probably the result of a redistribution of the attentional resources away from the occipital areas, which predominate in the resting state, evidenced as an increase in alpha amplitude over the occipital areas.

Alpha rhythm modulation by task demands was shown in posterior electrodes in visual and auditory attentional tasks [24-27] and in central posterior and bilateral areas with greater visual working memory load [24,28]. Although still controversial, the evidence suggests an effect of task demand in the amplitude of the alpha band. Surgical suturing can occur under self-paced conditions for simple sutures without time constraints or under fast-paced conditions, when there are time constraints and interferences that impose additional task demands. To the best or our knowledge, there is no evidence on the modulation of the alpha band with task-demands in complex visuo-sensorimotor tasks.

In addition, task expertise might modulate alpha amplitude in task-related areas. Changes in relative regional activation of brain areas have been observed in skill learning where practice and subsequent consolidation leads to reorganization of the functional architecture of the brain [26]. Expert drivers have smaller volume recruitment of task-related regions compared to novices [27]. For surgical suture, early stages of learning are characterized by prefrontal cortical activation, which attenuate with deliberate practice [26] and movements automation [7], in agreement with a modulation of the executive and attentional resources. For complex movements, behavioral measures of automaticity may disrupt the continuous flow of movements. An alternative approach for a correlate of automaticity is the Electroencephalogram (EEG) activity in the alpha-band [28,29]. In a laparoscopic surgical simulation, a continuous recording showed greater alpha power in the occipital area in efficient or fast- compared to non-efficient or slow-performers [30]. In summary, the evidence from surgeons suggests that greater performance might correlate with greater amplitude of alpha in posterior areas for complex movements.

In conclusion, complex visuo-sensorimotor tasks, such as suturing, involve the redistribution of the attentional resources away from the visual areas predominantly engaged in resting eyes-open condition, which might be modulated by expertise, task demand and/or movement efficiency. This redistribution should materialize in a greater synchronization in the alpha band in the posterior areas. We recorded scalp EEG of expert and novice surgeons to evaluate whether the alpha band (8-12 Hz) in the occipital area is modulated during continuous suture performance relative to resting and if this modulation is further shaped by surgical expertise, task demand and/or movement efficiency. We obtained the power of alpha in the occipital area and the number of sutures of surgeons and medical students while performing continuous open suture in both self-paced and fast-paced conditions and compared it with the resting condition. We hypothesized that alpha power should show (i) an effect of movement performance revealed by a greater alpha power in both surgeons and medical students in posterior areas for suture execution relative to resting; (ii) an effect of expertise revealed by a greater alpha power in surgeons relative to medical students, (ii) an effect of task demand revealed by a greater alpha power in both surgeons and medical students with high task demands and (iv) an effect of suture performance revealed by a positive association between occipital alpha activity and suture performance during suturing.

Methods

Participants

Thirty one participants with normal or corrected-to-normal vision participated in this study. Nineteen were medical students (8 women and 11 men, mean age of 23.1) and twelve were surgeons (5 women and 7 men, mean age of 49.5), all right-handed. All participants were recruited by invitation and gave written informed consent before the recording session.

The procedures were conducted following the Protocol #46-2020, approved by the Ethics Committee (Comité Ético Científico) of the Universidad de Talca, in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

Procedure

To evaluate the amplitude of the alpha oscillations in experts and novices surgeons, we performed EEG measurements while participants performed suture in both self-paced and fast-paced conditions as well as in resting condition. Novices were fourth-year medical students with 1 to 2 hours of standardized training in a suture workshop in the School of Medicine, University of Talca. Experts were established physicians with a minimum of 3 years and a maximum of 20 years with regular suture procedures practicing surgeons.

In a quiet room, participants were seated in front of a small table containing the surgery pad, tools and suture (Figure 1A). All participants were instructed on how to perform the sutures in a simulation model 3/0 of 75 cm (Braun a video the surgical technique) in a wound closure pad (Jig Mk 3 skin pad, Limbs and things, GA, USA), standard surgical instruments and 75 cm nylon 3/0 sutures (Braun Hessen, Germany) before recordings.

Scalp EEG recordings were obtained in 2 conditions: resting and open suture. In the resting condition, participants were quiet for 3 min with their eyes open. In the suture condition, participants performed 6 suturing trials of 5 minutes each (Figure 1B), divided into 3 trials of self-paced and 3 of fast-paced suturing with an inter-trial interval of 2 minutes. The sequence of the self-paced and fast-paced trials was randomized and balanced across participants. In self-paced suturing, participants were instructed to perform the sutures at their own pace and in fast-paced suturing, participants were instructed to perform the greatest number of sutures and received a comment every 60 sec indicating to increase the sutures because the other participates had better results.

EEG recordings

The electroencephalogram (EEG) was continuously recorded while participants completed all conditions, using a 32-channel BioSemi ActiveTwo system (BioSemi B.V., Amsterdam, Netherlands): scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P9, P7, P5, P3, P1, Pz, P2, P4, P6, P8, P10, PO7, PO3, POz, PO4, PO8, O1, Oz, O2, and Iz) according to the modified 10–20 System (American Electroencephalographic Society, 1994) plus 5 additional electrodes: left and right mastoids and 3 electro-oculogram (EOG) channels (at outer canthi of each eye, and below the right eye). All signals were recorded in single-ended mode. The EEG and EOG were low-pass filtered with a 5th-order sync filter (half-power cutoff at 208 Hz) and digitized at 1024 Hz.

Data analysis

Data analyses were conducted using a combination of EEGLAB [31] and ERPLAB [32], running on MATLAB 2015a (MathWorks, Natick, MA, USA). EEG signals were bandpass filtered offline using a non-causal Butterworth infinite impulse response filter, with half-power cutoffs at 0.1 and 40 Hz, and a roll-off of 12 dB/octave, and then down-sampled to 256 Hz. Eye-movement artifacts and eye blinks were corrected using Independent Component Analysis (ICA). Subsequently, scalp channels were referenced offline to the average of the left and right mastoids, and the three EOG signals, plus Fp2, were used to create two new bipolar vertical and horizontal EOG derivations, to explore remaining ocular artifacts.

For each EEG recording, the first 4 seconds of data were removed from all trials to minimize the presence of artifacts. After that, data segments of 2.5 and 4.5 minutes were extracted from resting and suture trials, respectively. The data from trials for suture conditions were merged for each condition resulting in 13.5 minutes of data. EEG data was subjected to a Fast Fourier Transform with a 4-sec, 50% overlap, Hanning-taper, artifact-free moving window. Power spectra with a number of averaged windows of less than 180 were eliminated from further analysis. The grand average power spectra (μV^2) were computed for each EEG channel for all recordings. Thus, based on the scalp distribution of alpha power (8-12 Hz) in occipital area (Figure 3), a ROI of three occipital electrodes (O1, O2 and Oz) was defined, and obtained a mean alpha for these electrodes. We additionally, evaluated the mean alpha power in a ROI for the central electrodes (C3, Cz, C4). Finally, mean power in the alpha band, from each participant's ROI, were compared across conditions. In addition, we obtained the number of sutures (stitches) from each participant, for each trial at each condition. The data from this study is available in http://dx.doi.org/10.17632/xb8fzmrf8j.1.

Statistical analysis

Statistical differences were estimated by Bayesian analysis using the Bayes Factor Toolbox for Matlab (https://github.com/klabhub/bayesFactor in Matlab written by Bart Krekelberg) based on Rouder et al. 2012 [33]. Statistical differences in power values were evaluated by a two-factor analysis of variance (ANOVA), with between-subjects factor of expertise (two levels: expert and novice) and within-subject factor of condition (three levels: resting, self-paced and fast-paced). Statistical differences between the numbers of sutures were evaluated using a two factor ANOVA. Main effects for the ANOVA were estimated as the ratio of the Bayes factors for the full model and the restricted model, obtained by excluding the factor from the full model. Differences between means were assessed as the Bayes factor (BF) for paired or unpaired t-tests. Bayes Factor for the H1 hypothesis equal or greater than 10 (H1 $\geq$ 0.90) indicates a strong evidence for the alternative hypothesis and a BF for the H1 between 3 and 10 was considered as moderate evidence for the alternative hypothesis.

To evaluate the association between alpha power and the efficiency of suture movements, we computed the Bayes factor for the Pearson product-moment correlation coefficient. A strong correlation was defined when r^2 values were equal or greater than 0.5, and a moderate correlation when r^2 values were between 0.45 and 0.5. Unless otherwise specified, all values are reported as mean $\pm$ SD in the main text and as mean $\pm$ SEM in the figures.

Results

The main goal of this work was to evaluate if the execution of complex movements modulates the amplitude in the alpha band relative to resting, and if this modulation was further shaped by expertise, task demand and suture performance. Alpha power and suture performance were compared in expert and novice surgeons in self-paced and fast-paced suturing and in resting conditions as an indicator of the redistribution of the inhibitory-attentional resources away from the occipital areas. From a total of 31 participants, 12 surgeons and 19 medical students, 2 from the medical student group were discarded due to the high noise in the EEG recordings. Consequently, we report the results from 12 surgeons and 17 medical students.

Suture performance

To evaluate the efficiency of suture movements, we obtained the mean number of sutures for each participant at each of three 5-minute trials in the self- and fast-paced conditions, (Figure 1).

As expected, surgeons had approximately twice the mean number of sutures than medical students in both self-paced (M = 10.2, SD = 2.1 vs M = 4.6, SD = 1.5, respectively) and fast-paced (M = 12.1, SD = 1.5 vs M = 5.5, SD = 1.1, respectively) conditions (Figure 2).

Moreover, the number of sutures was greater in fast-paced relative to self-paced condition surgeons and medical students. The 2 x 2 repeated-measures ANOVA on the number of sutures with between-subject factor of expertise (surgeons, medical students) and within-subject factor of task demand (self-paced, fast-paced) show main effects of expertise ($F(1, 54) = 18.2$, BF = $3.4 * 10^{10}$) and task demand ($F(1, 54) = 17.4$, BF = 134.6), and no interaction between expertise and task demand ($F(1, 54) = 3.2$, BF = 0.53). These results demonstrate that surgical expertise increases suturing performance and that higher task demands add an extra boost to performance. Post-hoc tests confirm that the number of sutures was greater in surgeons (BF = $1.6 * 10^{16}$, probability from data for the alternative hypothesis, PH1 > .99, unpaired t-test) than in medical students when data was pooled across task demands and that a greater demand in the fast-paced condition increased the number of sutures (BF = 80.5, PH1 > .98, paired t-test) when data from surgeons and medical students were pooled. Moreover, greater demand increases the number of sutures by 20 % in surgeons (BF = 8.1, PH1 = .89, paired t-test), but our data does not support an effect of task demand in performance (BF = 2.8, PH1 > .74, paired t-test) for medical students. In summary, these results demonstrate that surgical expertise almost doubles the speed of suture movements and that a greater task demand increases the speed of movements in surgeons.

Modulation of the alpha rhythm

The average scalp maps of the power in the alpha band for surgeons and medical students, plotted with ERPLAB [32] / EEGLAB [31], are shown in Figure 3. In surgeons, a baseline alpha power in posterior electrodes O1, O2 and Oz was observed in resting (R), eyes open condition. The alpha power in the posterior electrodes increased during suture movement execution in self-paced (SP) and fast-paced (FP) conditions (Figure 3A). A similar pattern was obtained in medical students (Figure 3B).

To quantify the variation in the alpha power in open suture, a ROI in the occipital area (O1, Oz and O2, see methods section) was defined based on the scalp distribution. The mean alpha power for each ROI for resting, self-paced and fast-paced suturing is shown in Figure 4. In surgeons, alpha power was higher during suturing for both self-paced and fast-paced conditions (M = 6.63, SD = 4.21, and M = 8.66, SD = 6.02, respectively) relative to resting (M = 4.47, SD = 2.47, Figure 4). Likewise, alpha power was higher in medical students when suturing in self-paced and fast-paced conditions (M = 9.50, SD = 6.96, and M = 10.64, SD = 7.49 s, respectively) relative to resting (M = 5.45, SD = 3.83, Figure 4).

The 2 x 3 ANOVA for the individual alpha power values with between-factor of expertise (surgeons, medical students) and within-factor of task type (resting, self-paced, fast-paced) showed a main effect of task type ($F(1, 83) = 8.0$, BF = $1.34*10^3$), no effect of expertise ($F(1, 83) = 0.54$, BF = 0.26), and no interaction between expertise and task type ($F(1, 83) = 0.26$, BF = 0.08). These results indicate that suturing increases the power in the alpha band in the occipital electrodes relative to resting and that alpha power was not additionally modulated by expertise and task demand. Post-hoc tests show a greater alpha power in self-paced (BF = 9.4, PH1 = .90, paired t-test) and fast-paced (BF = 145.0, PH1 > .99) suturing relative to resting, but no difference in alpha power between self-paced and fast-paced suturing (BF = 1.7, PH1 = .63), after collapsing for expertise. In summary, our results show that switching from resting to open suturing increases the amplitude of the alpha band in the occipital electrodes, in agreement with a redistribution of the attentional resources away from occipital areas during suture execution.

Moreover, because alpha activity is modulated by hand movements in sensorimotor cortex [9,11,12], we evaluated the alpha power in a ROI for the central electrodes (C3, Cz, C4). In surgeons, the mean alpha power was M = 1.49, SD = 0.90, M = 1.44, SD = 0.81, and M = 2.07, SD = 2.59, in resting, self-paced and fast-paced conditions and in medical students the alpha power was M = 3.11, SD = 5.41 M = 1.46, SD = 0.91, and M = 1.60, SD = 1.09, in resting, self-paced and fast-paced conditions. The ANOVA indicated no main effect of expertise (F(1, 83) = 3.26, BF = 0.01) and task type (F(1, 83) = 0.68, BF = 0.07), and no interaction between these factors (F(1, 83) = 4.25, BF = 0.64). Summarizing, the mean alpha power in the sensorimotor areas was not modulated in continuous suturing.

Association between the alpha rhythm and suture performance

We show that surgical expertise increases the efficiency of surgical movements and that the execution of surgical suture increases the strength of alpha activity in the occipital areas in both surgeons and medical students. Besides, suturing efficiency was strongly modulated by task demand in surgeons but not in medical students, which could indicate that expert surgeons may have a greater control of movement efficiency. In parallel, there as a trend for greater alpha power over occipital areas with increasing task demand, suggesting an association between movement efficiency and alpha power in the occipital areas as observed in laparoscopic movements [10]. To test for a relationship between the alpha amplitude and suture efficiency, we assessed the correlation of the occipital alpha power during suturing with suture efficiency in surgeons and medical students. The scatterplot of the individual alpha power values in surgeons and medical students in relaxed and high-demand conditions as a function the number of sutures is shown in Figure 5.

However, our results do not support the modulation of mean alpha amplitude by expertise and task demand.

The Pearson correlation coefficient show a linear positive correlation between the individual alpha power and the number of sutures for surgeons ($r^2(22) = 0.55$), with a moderate statistical evidence from the data (BF = 6.81, pH1 = .87), suggesting that as the suture efficiency increases, there is a greater power in the alpha band. In contrast, our data does not support the correlation in medical students ($r^2(32) = 0.35$, BF = 1.0, pH1 = .50). These results suggest that greater movement performance during suturing associates with increases in occipital alpha power for expert surgeons.

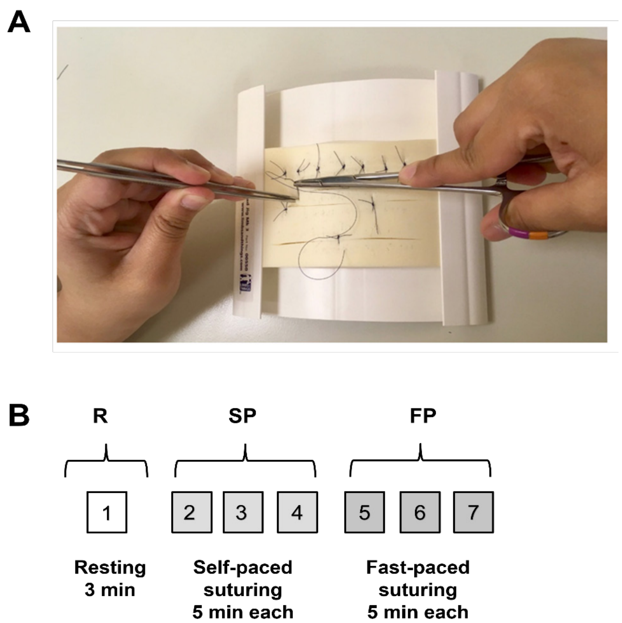

Figure 1: (A). Experimental setting showing a participant performing sutures in a wound closure pad with standard surgical instruments. **(B)**. An example of a trial sequence, resting (R), self-paced (SP) or fast-paced (FP) suturing conditions. The order of the conditions (SP and FP) were randomized.

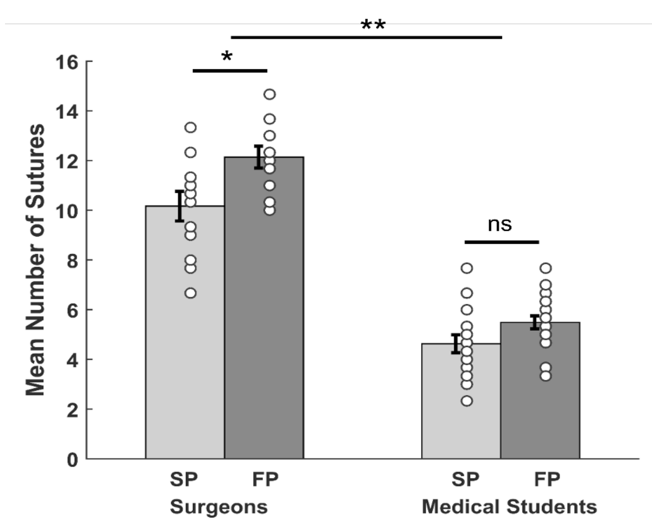

Figure 2: Mean number of sutures in surgeons and medical students under different task demands. Mean number of sutures in surgeons and medical students in self-paced (SP) and fast-paced (FP) suturing. Error bars are standard error of the mean (SEM). Asterisks indicate statistical differences between means (** Probability from data for H1 > 0.9, * Probability from data for H1 > 0.85, ns non-significant).

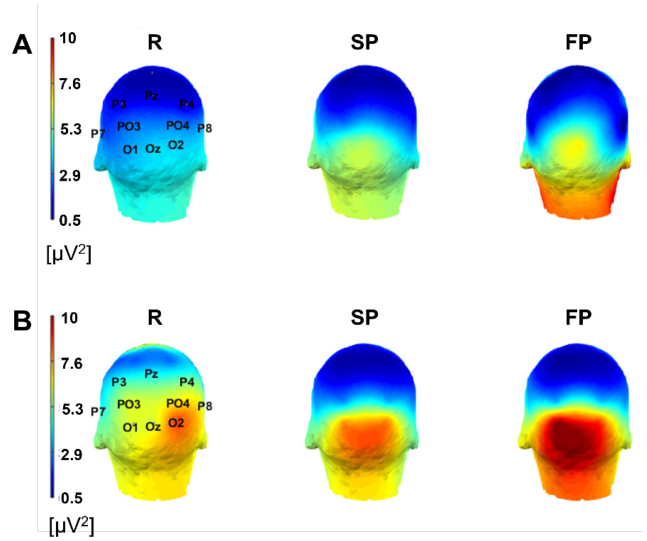

Figure 3: Grand-average scalp maps of surgeons and medical students at resting and suturing in different conditions. A. Scalp maps from surgeons, B. Scalp maps from medical students. Resting (R), self-paced (SP) and fast-paced (FP) suturing.

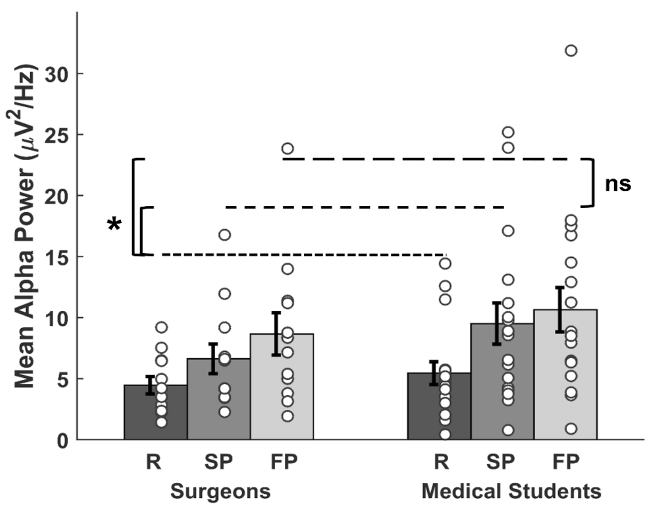

Figure 4: Individual and mean alpha power values for surgeons and medical students in different conditions. Individual and mean alpha power in resting (R), self-paced (SP) and fast-paced suture (FP). Error bars are SEM. Asterisk indicate statistical difference between means (*, Probability from data for H1 > 0.90, ns non-significant).

Discussion

We evaluated whether alpha amplitude in the posterior areas is modulated by movement execution, expertise and task demands in a continuous complex visuo-sensorimotor task. To do so, we obtained the number of sutures, as a measure of the efficiency of movements and the mean alpha power, as an estimate of the redistribution of attentional resources, in self-paced or low-demand suturing and fast-paced or high-demand suturing and resting eyes open condition in expert and novice surgeons.

As expected, we show that surgical expertise markedly increases the total number of sutures indicating a greater movement efficiency in both self-paced and fast-paced suturing and

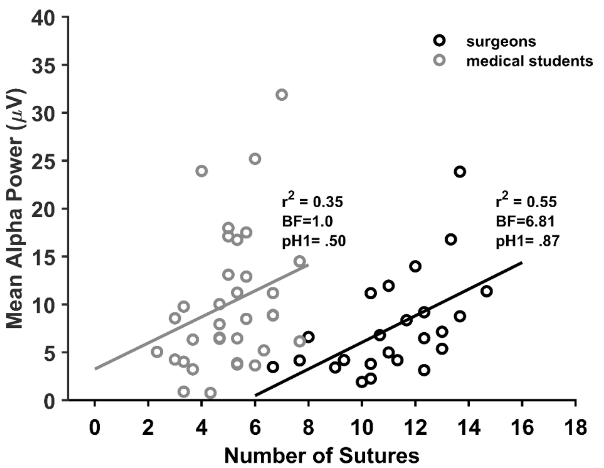

Figure 5: Association between Alpha power and the number of sutures in surgeons and medical students. Pearson correlation of the individual alpha power and the number of sutures including the data from self-paced and fast-paced conditions for surgeons and medical students. Lines represent a linear regression.

that greater task demand in fast-paced suturing further enhances the total number of sutures in expert surgeons, but not significantly in medical students. Second, we show an increase in the amplitude of the alpha band in the posterior electrodes during suture performance relative to resting in both, surgeons and medical students, in agreement with a task associated redistribution of the attentional resources. In addition, expertise and task demand do not further modulate alpha power, indicating no additional effect on the redistribution of attentional resources. Finally, alpha amplitude correlated positively with the number of sutures only in surgeons, suggesting a linear dependency between the redistribution of the attentional resources and movement efficiency. In the following paragraphs we address each of the findings.

Regarding open suture, surgical expertise nearly doubled the number of sutures, a behavioral measure of movement efficiency, relative to medical students in both self-paced and fast-paced conditions (Figure 2)**,** in agreement with previous evidence of a greater precision and lower variability of expert motor execution in expert surgeons [2-5,34-36]. The difference in performance between novices and experts likely reflect the difference from goal-directed and habit-directed movements, respectively, which involve distinct patterns of cortical and subcortical activation [7,8,37]. Task demand further modulates the number of sutures by 20 % in surgeons (Figure 2) in response to the instruction to achieve superior number of sutures as well as the interference in the form of comparative comments with other participants, indicating that experts can additionally speed up movements. In contrast, our data does not support an effect of task demand in medical students, even with a larger sample size (N = 17), presumably due to greater variability in movement performance in low and high demand conditions. In conclusion, the long-term effect of expertise improves suture performance by 100 % and the short-term effect of task-demand improves performance by an additional 20% in experts.

Regarding the power in the alpha band, execution of a continuous complex visuo-sensorimotor task results in an overall alpha synchronization (Figure 4) in the occipital electrodes (Figure 3) in both, surgeons and medical students, relative to resting. These results are consistent with previous studies showing synchronization in the posterior electrodes for simple finger or foot movements [11,12] and movement observation [14]. Similar effects were observed in motor [38], somatosensory [39], auditory [40,41], visual attention [21,22] and internal/external attention tasks [42]. The greater alpha amplitude is not consistent with full inhibition of “task irrelevant” occipital areas because visual input is required for suture movements. Alternatively, our results suggest a redistribution of limited attentional resources throughout cortical areas when switching tasks from resting to open suture, as observed when closing the eyes in complete darkness [42] or when directing attention internally [24,25], in agreement with the attentional theory of the alpha rhythm [17,18].

In contrast, expertise does not modulate the mean alpha power (Figure 3), suggesting that the difference in motor control between novices and experts does not impact the redistribution of attentional resources away from occipital areas. Imaging of motor skill acquisition has shown substantial changes in brain activation between the initial and later stages of learning, indicating a gradual transition from goal- to habit-like movements [8,37]. Medical students in the early stages of skill learning, probably perform open sutures trough goal-like movements entailing a high activation of the anterior areas involved in attentional control and executive function [43-47]. Meanwhile, expert surgeons probably perform sutures trough habit-like movements with greater activation of the sensory areas and basal ganglia and lower activation of the frontal cortex [8,37,38]. In conclusion, our results suggest that although different expertise levels in open suture involve substantial differences in brain processing, these differences are not expressed over the mean alpha power in the posterior occipital areas.

Likewise, task demand elicited no additional modulation of the mean alpha band (Figure 4), suggesting that the processes engaged in the redistribution of attentional resources over the posterior electrodes were not shaped by task demand in agreement with previous results [25]. In conclusion, task demand did not modulate the overall alpha band in the occipital areas.

In addition to the effect of movement execution on the alpha power, our results suggest a modulation by movement efficiency in expert surgeons, in agreement with the general increase in alpha power in posterior electrodes in a somatosensory discrimination task [23]. Our data from 12 surgeons show a positive linear association between alpha power in the posterior areas and the number of sutures. Although with a moderate statistical support from the data, these results suggest that the extent of experts’ attentional redistribution away from the occipital areas in open suture is associated with movement efficiency, in agreement with a greater alpha power in the occipital regions in good performers obtained in laparoscopic surgery [30]. Moreover, imaging of movement speed revealed the activation of multiple cortical and subcortical areas, with slow movements involving the prefrontal areas bilaterally and fast movements involving the sensorimotor cerebral cortex [49,50], excluding the posterior occipital areas. Additional studies with a greater sample size should be performed to confirm this association. In contrast, our data does not support this association in medical students, probably because of the different processes involved in movement execution and because there is no significantly higher movement efficiency for fast-paced condition despite the larger sample size.

Because simple movements trigger increases and decreases of alpha synchronization in the somatosensory and motor areas within a movement cycle [9,11,13,15], we also evaluated alpha activity over the central electrodes (C3, Cz and C4) in the somatosensory areas during suture execution. We found no difference in the mean alpha amplitude for suture execution, and no effect of expertise and task demand, as anticipated for a continuous recording of alpha power in the suturing trials where amplitude modulations should cancel-out throughout the suturing exercise.

While the results presented here contribute to the understanding of the modulation of the alpha rhythm in the occipital areas in a more ecological setting, consisting in a continuous execution of complex movements and its relationship with movement performance, they also have several limitations. First, we obtained the mean alpha power in the occipital areas during continuous suture movements not stereotyped across time and participants, hindering the identification EEG signals associates to specific movements' phases. The failure to associate the time course of the alpha power for complex movements is clearly a limitation of this study, particularly for the central electrodes located over the somatosensory and motor control areas of the hand [13].

Future studies should evaluate the time course of alpha amplitude in different cortical areas for specific movement phases. Second, our study had a small sample size of expert surgeons (N = 12), despite the efforts set in the recruitment. Several limitations of small sample sizes include an overestimation of the effect size and more type II errors [52]. To reduce the effect of a limited sample size, we performed Bayesian statistics whose outcomes (Bayes Factors) indicate the support of the data for the null and alternative hypothesis. Because of the small sample limitation, further studies should be done to corroborate the modulation of the alpha amplitude in open suture. Finally, the mean age of surgeons and medical students was different, but we found no statistical difference in the mean alpha power for resting, indicating that the age difference of surgeons and medical students was not a source of variability for the alpha power for resting baseline condition.

Conclusions

In summary, here we provide evidence for the synchronization in the alpha band in the occipital areas in open suture, both in surgeons and in medical students relative to the resting and its association with the efficiency of movements. Surgeons are twice as efficient in the number of open sutures, likely due to movement automation. High task-demand increases suture efficiency by 20% only in surgeons, in agreement with additional movement speed enhancement in expert surgeons. Interestingly, the overall mean amplitude of EEG alpha band is greater for suturing relative to resting, although it is not modulated by expertise and task-demand, in agreement with a redistribution of the attentional resources away from occipital areas during movement execution. Surgeons have a positive linear association between the occipital alpha amplitude and suture efficiency, suggesting that visuo-sensorimotor expertise may reshape the relationship between movement execution and alpha-related networks. In contrast, medical students have no association between alpha amplitude and movement efficiency, likely based in a greater complexity in the control of suture movement. Taken together, these findings are consistent with the redistribution of limited-resources held by the inhibitory-attentional theories of alpha rhythm in a complex visuo-sensorimotor task.

Declarations

Conflicts of interest: The authors declare that they have no conflicts of interest.

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Authors' contributions: SR designed the experiment, collected and analyzed the data, edited the article; MQ collected and analyzed the data; JK analyzed the data and wrote the article; JLC analyzed the data and wrote the article; MLA designed the experiment, analyzed the data and wrote the article. All authors read and approved the final manuscript.

Ethics approval and consent to participate: The procedures were conducted with Protocol #46-2020 in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki). The study was approved by Scientific Ethic Committee (*Comité Ético Científico)* of the Universidad de Talca. All participants were recruited by invitation and gave written informed consent before the recording session.

Availability of data and materials: The datasets supporting the conclusions of this article are available in the Mendeley repository, Reyes, Sergio; Quinones, Matias; Kreither, Johanna; Lopez-Calderon, Javier; Aylwin, Maria (2021), "Alpha Waves Open Suture", Mendeley Data, V1, DOI: 10.17632/xb8fzmrf8j.1

Abbreviations: EEG: Electroencephalogram; EOG: Electro-Oculogram; R: Resting; SP: Self-Paced; FP: Fast-Paced; ROI: Region of Interest; BF: Bayes Factor; ANOVA: Analysis of Variance; SD: Standard Deviation; SEM: Standard Error of the Mean

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