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Train the Brain: Novel Electroencephalography Data Indicate Links between Motor Learning and Brain Adaptations

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Abstract

EEG differences were examined between part and whole practice in the learning of a novel motor task. Recording was done at 4 sites (i.e., O1, O2, C3, and C4) on 30 participants who performed a novel mirror star tracer task. Individuals were randomly assigned to 3 groups: whole practice, part practice, and control (no practice). Whole practice is defined as practicing a skill in its entirety. Part practice is defined as practicing separate, independent parts of the skill, and gradually combining those parts with parts that are dependent on one another. Each group was assessed during a pretest and posttest. EEG data was analyzed using a 2×2×2×3 (trials×hemisphere×site×practice) repeated measures mixed model ANOVA for each of the wave bands (lower alpha, upper alpha, lower beta, upper beta). All participants performed the task faster as no practice effect was found across the three groups; however the part practice group exhibited a significant decrease in errors. Reduced activation in the occipital and central sites was observed for lower alpha in the posttest compared to the pretest, for all participants. Hemispheric differences were present for all wavebands, with greater activation in the left hemisphere independent of practice type. The results of our study indicate that task learning was likely associated with the observed changes in the lower alpha waveband. Further, a concomitant behavior between the hemispheric lateralization of alpha and beta waveforms was observed. These results have implications for athlete training and rehabilitation. They indicate the utility of EEG for learning assessment in athletes. They also indicate learning strategies with a partial movement focus may be a beneficial strategy to support the development of complex sport skills training and rehabilitation strategies focused on reacquisition of skills prior to sport reintegration.

Keywords: EEG; Learning; Neuromuscular training; Practice; Sport performance

Introduction

Research in motor learning has been performed with nonfunctional, non-novel tasks involving movements that have already been established in the abilities of individual performers [1]. These tasks generally require individuals to utilize existing movement patterns or adaptations instead of forcing them to fully learn new skills (e.g., shooting a basketball, learning a tennis stroke, or adapting a previously learned movement). Rarely is a true novel skill being learned, even though many of these tasks are defined as novel or new [1]. Moreover, skill performance is usually judged in two specific ways that aid in the determination of learning [2]. The first is through outcome or results following the completion of the task, while observing both time to completion and errors (i.e., time on target). The second method uses continuous psychophysiological measures to provide real time accounts for the physiological responses that take place during learning.

Within psychophysiology, one tool that is available to measure learning changes is electroencephalography, or EEG [3,4]. EEG changes have been found to occur during various mental activities [5], are collected in real time, and provide solid supplements to verbal protocols currently used in motor learning and sport psychology [6]. Specifically, EEG activity is measured by EEG signal power in μVolts^2 and increased activity equates to greater power measured from a given electrode, and vice versa. In particular, different patterns of EEG power at different frequencies can be observed during different types of attention and even during the readiness and reaction periods prior to and during the performance of a skill. These patterns show that analysis of EEG variations can be strictly related to specific behavioral elements within the individual [7].

Alpha and beta frequencies are two sinusoidal waves within the study of EEG that can be used to characterize these behaviors. Alpha waveforms generally occur between 8 to 13 Hz and are detected when an individual is awake, relaxed, and in an environment relatively free of stimuli [8]. Beta waveforms include all frequencies between 13-30 Hz and can exist simultaneously throughout the cortex at various frequencies [9]. Alpha and beta waves have both been found to accompany cognitive processing, especially those related to the various sensory cortices [10]. These rhythms are also generally thought to hold an inverse relation, such that when alpha rhythms are higher, beta rhythms are lower and vice versa [11]. However, this relation is unclear as Klimesch et al. [12] reported that when appropriately analyzing the alpha and beta frequency bands, there is a concomitant behavior between alpha and beta desynchronization.

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In the last fifteen years it has been further revealed that there exist two separate alpha components, with two specific ranges of frequencies: (1) Upper alpha (11–13 Hz) and (2) lower alpha (8–10 Hz). Upper alpha is a waveband that responds to stimulus perception, while lower alpha indicates lower cognitive processing and lower levels of arousal, attention, and effort [12]. Beta has also been found to have two distinct bands as well: (1) upper beta (22–31 Hz) and (2) lower beta (14–21 Hz). Upper beta reflects high levels of arousal, while lower beta is generally indicative of sensory stimulation [13]. When conducting research on alpha and beta wave frequencies in the context of learning, this split-band perspective may provide a clearer insight into the relation between EEG activity and motor learning. Further, hemispheric lateralization has been examined across different tasks, with the right-hemisphere thought to be more involved in visuo-spatial tasks while the left hemisphere is more involved in the processing of verbal or analytical material [14]. However, Rebert et al. have demonstrated more stable, alpha power during the playing of a Pong video-game—a high visuo-spatial task [15].

Practice type is also an important component to motor learning assessment, and a widely discussed and effective type of practice is whole/part practice. This is defined as practicing separate, independent parts of the skill, and then combining those independent parts with parts that are dependent on one another [2]. When determining the effectiveness of the whole/part practice technique, the skill must be assessed in order to determine which type of practice (whole or part) will likely be more effective. This, in turn, is determined by two distinct characteristics of motor skills: complexity and organization. Motor skill complexity is defined as the number of parts or components of a skill; meaning the more parts or components a skill has, the higher it is in complexity. Motor skill organization is defined as how dependent sequences, or parts, are to a specific skill. When performance of one part of a skill depends on what precedes or follows that particular part, the skill is considered higher in organization. When comparing the effectiveness of whole versus part practice, the whole practice method is the most effective type of practice to facilitate the learning of a low complexity, low organization motor task [2]. Conversely, part practice is most effective for low-organization, high complexity tasks.

There is potential utility for recording EEG activity during learning to improve athlete training and rehabilitation protocols. For example, new learners transition from internally focused attention (when a performer's attention is directed toward their actual movements) to more externally focused attention that is directed toward an outcome, or the effect(s), of the movement being produced (e.g., a goal, target, or intended outcome) [16,17]. This stage of motor acquisition may be associated with a learner's ability to ground the training, or motor skill, in the broader performance context and thus improves the learner's utilization of feedback. Therefore, a better understanding of attention responses to training foci and feedback can help optimize neuromuscular training strategies and their desired adaptations. Accordingly, identifying the transitions in attention through psychophysiological responses, and specifically alpha and beta activity, during motor skill performance can identify landmarks in the learning process, and may signal an opportune time to change or adapt feedback to the learner.

While some scientific evidence exists regarding the use of EEG in determining the physiological responses to learning [3,4,18], to our knowledge there are no studies that have addressed the issue of whole versus part practice. Furthermore, measuring both alpha and beta waves may offer new insight into the processes that occur during the learning of a novel task, specifically when examining whole versus part practice techniques. The purpose of this study was to determine EEG differences between whole and part practice methods in the learning of a novel motor task. It was hypothesized that there would be a significant increase in lower alpha activity at the left central and occipital sites for the whole practice group when comparing the pre-test to the post-test. Our corollary hypothesis was that there would be a significant decrease in upper beta and lower beta at the left central and occipital sites for the whole practice group when comparing the pre-test to the post-test.

Method

Participants

The participants (N=30; 15 females and 15 males) for this study were students and staff at a university in the southeastern United States. The participants were from 18-30 years of age and were all right-handed. These participants had no history of mental illness, learning disabilities, or motor control issues that could hinder their performance in the required novel motor task. All participants did not exercise, smoke, or take medications/drugs within 24 hours of testing.

Instrumentation

EEG signals were collected using the Biopac MP150 unit (Biopac Systems Inc.). Grass Telefactor silver-silver chloride cup electrodes were used with ear references for both the right and left hemispheres. This unit allows for up to 16 channels of analogue inputs with an input impedance of 1.0 M Ohm. Data were sampled at a rate of 200K samples/second (400K aggregate) with an internal buffer of 6M samples (12 MB). The Ethernet DLC Type II interface allowed 10M Bits/sec on a Windows operating system. A 10/20 montage was used [19], and the EEG data were analyzed using Acknowledge software version 3.7.3. The data were collected at four sites (O1, O2, C3, and C4) with a bandpass filter of 8-30 Hz, and average referenced to mastoid sites (Figure 1, left). Electrooculography was collected to detect eye movement artifacts so that the effected data could be discarded prior to analysis. There were two cup electrodes used to collect this data positioned 1.5 cm perpendicular and horizontal to the pupil of the right eye (Figure 1, right). Post-processing of data was done through customized Matlab routines in order to obtain Fast Fourier Transform values.

Mirror tracer task

The performance of participants was measured using an Automatic Scoring Mirror Tracer (Model 58024A, Lafayette Instrument Company, Lafayette, IN). The mirror tracer is a quantitative measure of upper limb control and requires the participant to coordinate their upper-

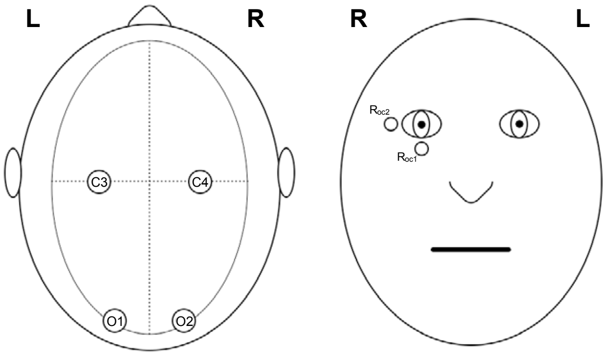

Figure 1: A schematic of the EEG electrode placement for the C3, C4, O1, and O2 sites (left) and the EOG electrode placement around the right eye (right).

arm movements in such a way as to follow a star shape by tracing the star's outline based on visual feedback from the star's reflection in the mirror. The participants were required to hold a metal stylus and trace the outline of a 5-point star using their dominant hand. The star was painted in non-metallic black paint on a metal surface, and any time the stylus left the surface of the star, an electronic counter would automatically score an error. Two performance measurements were taken: (1) total time it took to complete the tracing of the star and (2) errors (the number of times the stylus was off of the star line). The star tracer has been used in various studies on motor learning and practice [3,20] due to it being recognized as a true novel task. It is considered a novel task because participants are required to trace a 5 point star with their only view of the star and their hands provided through a mirrored reflection due to a 6" metal panel blocking the actual star and hand from the participant's view. In the context of the current experiment, the parts of the star are completely independent of one another, and these parts can be simplified into smaller tracing groups in order to practice the task.

Procedures

On the day of the experiment, participants read and signed the informed-consent form and sat quietly while the four electrodes were attached to their scalp. Participants were then given task instructions. They were randomly assigned to a whole practice group, a part practice group, or the control group. Participants were assessed on the mirror tracer task prior to any intervention while EEG was recorded during an initial pretest. Ten line segments made up the perimeter of the star being traced. Participants were required to complete the star in the minimum amount of time possible. Once the participants had been assessed they received one of the three practice interventions. The whole group was required to practice the entire task 50 times, meaning they traced 500 line segments. The part group was required to practice two line segments on 1/5 of the star task, two segments on a separate 1/5 of the star task, and so on. These pairs were randomly assigned to the participants, and the participants completed each pair ten times for a total of 50 times, which meant they traced 500 line segments over the 10 line segments of the star as well. However, they never practiced the entire task from beginning to end. The control group sat quietly for 10 minutes (the amount of time it took the other groups to practice) but did not receive an actual practice intervention. Instead, these participants read a passage requiring some cognitive processing. Following the intervention, each group was then re-assessed on the mirror star tracer and their EEG was measured during the post-test following the same conditions as in the pretest.

Design and analysis

There was a two second epoch extracted during the first third of the total time, a two second epoch extracted during the second third of the total time, and finally a two second epoch extracted during the final third of the total time it took for the participant to complete the task. Each epoch was taken from the middle of each section that was free of artifact and the average was calculated, with a total of 36 seconds used in the final data analysis. This is considered a valid amount of data points since past research [21] has revealed that 20 seconds of activity are sufficient to reduce adequately the variability inherent in the EEG. A fast-Fourier transform (FFT) was conducted on each section to determine EEG activation.

The performance outcome data was analyzed using two 2 (pre- vs. posttest)×3 (whole vs. part vs. control) repeated-measures mixed model analysis of variance (ANOVA) for each of the dependent variables (time and errors). A logarithm was used to transform the EEG data prior to further analysis. Separate 2 (trials)×2 (right vs. left hemisphere)×2 (occipital vs. central site)×3 (practice) repeated measures mixed-model ANOVAs were conducted for each one of the wave bands (i.e., lower alpha, upper alpha, lower beta, upper beta). The dependent variables were the lower and upper alpha/beta waves associated with learning during each of the practice methods (i.e., whole/part). The independent variables were the trials (i.e., pre/posttest), sites (i.e., O1, O2, C3, and C4), hemispheres (i.e., right and left), and practice methods (i.e., whole/part).

Results

Performance data

A significant main effect was found for trials with respect to time, F (1,27)=78.12, $p<.001$ (pretest M=38.01 ± 2.9 seconds; posttest M=23.35 ± 1.71 seconds) and indicated that the time was significantly less during the posttest. A significant main effect was found for trials with regard to errors as well, F (1,27)=6.432, $p<.05$, (pretest M=7.95 ± 0.89 errors; posttest M=6.69 ± 0.79 errors) with significantly fewer errors during the posttest. A significant main effect was also found for practice, F (2,27)=190.77, $p<.05$). A Tukey Post-Hoc was run significant differences were found between the whole and part practice groups ($p<.05$). Table 1 shows the means and standard deviations for pre and post time and errors.

Lower alpha power

A main effect of site was observed, F (1,27)=31.70, $p<.001$, in the lower alpha frequency (occipital M=2.66 ± .415 μVolts^2; central M=2.35 ± .271 μVolts^2), and indicated greater occipital than central activity. A main effect of hemisphere was also found for the lower alpha waveband, F (1,27)=15.70, $p<.001$, (right hemisphere M=2.43 ± .333 μVolts^2; left hemisphere M=2.58 ± .322 μVolts^2), and demonstrated a larger amount of activity in the left hemisphere. A significant trials×site interaction was also present, F (1,27)=4.84, $p<.05$. A follow-up paired samples t-test compared the mean pretest score for the occipital site to the mean posttest score for the occipital site. A significant decrease from pretest to posttest was found, $t(29)=2.108$, $p<.02$ (pretest M=2.708 ± 0.45; posttest M=2.619 ± 0.41 μVolts^2). Similarly, a follow up paired samples *t*-test was also calculated to compare the mean of the occipital posttest score to the mean of the central posttest score, and indicated a significant difference, $t(29)=4.405$, $p<.001$) (occipital posttest score M=2.619 ± 0.41 μVolts^2; central posttest score M=2.35 ± 0.27 μVolts^2).

Upper alpha power

A main effect of site was found in the upper alpha band, F (1,27)=40.881, $p<.001$ (occipital site M=2.83 ± 0.42 μVolts^2; central site M=2.42 ± 0.30 μVolts^2), and indicated higher occipital activity than central activity. A main effect of hemisphere was also found, F (1,27)=9.814, $p<.005$; (right hemisphere M=2.54 ± 0.37 μVolts^2; left hemisphere M=2.71 ± 0.32 μVolts^2), and indicated a larger amount of activity in the left hemisphere when compared to the right hemisphere.

Lower beta power

A main effect of site, F (1,27)=55.56, $p<.001$, was found for the lower beta band (occipital site M=2.83 ± 0.34 μVolts^2; central site M = 2.38 ± 0.28 μVolts^2), and indicated higher occipital activity than central activity. A main effect of hemisphere was also found, F (1,27)=6.82, $p<.05$ (right hemisphere M=2.55 ± 0.30 μVolts^2; left hemisphere M=2.66 ± 0.27 μVolts^2).

Dependent Variable	Whole	Pretest Part	Control	Whole	Posttest Part	Control
Time (s)	38.76 (13.39)	38.61 (13.57)	36.68 (20.10)	20.11 (9.45)	24.77 (9.10)	25.43 (9.52)
Errors	4.40 (2.63)	11.80 (6.18)	7.60 (5.13)	4.10 (2.96)	9.00 (4.92)	7.10 (4.36)
Lower Alpha (µVolts^2)						
R, Occipital	2.36 (0.52)	2.88 (0.48)	2.71 (0.40)	2.41 (0.32)	2.63 (0.55)	2.67 (0.42)
L, Occipital	2.61 (0.37)	2.91 (0.59)	2.77 (0.48)	2.45 (0.32)	2.80 (0.55)	2.76 (0.51)
R, Central	2.09 (0.43)	2.27 (0.27)	2.38 (0.44)	2.18 (0.14)	2.22 (0.30)	2.38 (0.39)
L, Central	2.40 (0.26)	2.39 (0.22)	2.60 (0.31)	2.36 (0.25)	2.35 (0.29)	2.60 (0.37)
Upper Alpha (µVolts^2)						
R, Occipital	2.46 (0.57)	2.82 (0.54)	2.87 (0.33)	2.64 (0.49)	2.86 (0.52)	2.86 (0.29)
L, Occipital	2.75 (0.35)	3.12 (0.63)	2.88 (0.42)	2.72 (0.37)	3.04 (0.60)	2.94 (0.48)
R, Central	2.19 (0.46)	2.27 (0.33)	2.42 (0.43)	2.29 (0.25)	2.32 (0.39)	2.50 (0.39)
L, Central	2.39 (0.31)	2.45 (0.29)	2.69 (0.30)	2.37 (0.34)	2.42 (0.28)	2.73 (0.41)
Lower Beta (µVolts^2)						
R, Occipital	2.61 (0.44)	2.88 (0.37)	2.86 (0.32)	2.70 (0.39)	2.81 (0.42)	2.86 (0.25)
L, Occipital	2.74 (0.32)	3.10 (0.46)	2.87 (0.34)	2.70 (0.31)	2.97 (0.52)	2.81 (0.35)
R, Central	2.23 (0.32)	2.24 (0.35)	2.42 (0.42)	2.31 (0.25)	2.25 (0.32)	2.38 (0.35)
L, Central	2.40 (0.33)	2.40 (0.34)	2.64 (0.28)	2.35 (0.33)	2.39 (0.31)	2.58 (0.41)
Upper Beta (µVolts^2)						
R, Occipital	2.66 (0.42)	2.74 (0.38)	2.71 (0.31)	2.77 (0.40)	2.71 (0.44)	2.73 (0.20)
L, Occipital	2.75 (0.32)	2.97 (0.49)	2.76 (0.32)	2.75 (0.31)	2.90 (0.58)	2.71 (0.35)
R, Central	2.22 (0.47)	2.09 (0.37)	2.32 (0.37)	2.26 (0.43)	1.98 (0.44)	2.29 (0.33)
L, Central	2.31 (0.44)	2.18 (0.40)	2.54 (0.36)	2.32 (0.38)	2.15 (0.51)	2.52 (0.35)

Note. All values represent the mean of each measure, with standard deviation in parentheses. R=Right; L=Left.

Table 1: Shows the means and standard deviations for time on task, errors, and all four EEG sites (C3, C4, O1, and O2) for the lower alpha, upper alpha, lower beta, and upper beta wavebands.

Upper beta power

In the upper beta waveband a main effect was found for site, F (1,27)=53.92, $p<.001$ (occipital site M=2.75 ± 0.34 µVolts^2; central site M=2.24 ± 0.37 µVolts^2), and indicated higher occipital activity than central activity. A main effect of hemisphere was also found, F (1,27)=6.88, $p<.05$ (right hemisphere M=2.43 ± 0.35 µVolts^2; left hemisphere M=2.56 ± 0.30 µVolts^2), and demonstrated a larger amount of activity in the left hemisphere compared to the right hemisphere.

Discussion

This study was designed to determine EEG differences between part and whole practice methods during the learning of a novel motor task. Methods used to facilitate learning are substantial contributors to the learning process. Practice is one such contributor used to facilitate the learning of a new skill, and this study suggests that EEG can lead to inferences with regard to the learning of a new skill.

Performance summary measures

On one hand, the results of the analysis on time performance indicated that participants in all groups significantly improved from their pretest times to their posttest times; however, there were no significant time differences between the three practice groups. One reason for this may be due to the low complexity of the mirror star tracer task. This lack of complexity may have hindered separation of proficiency among groups leading to results that were not significant with regard to each group. Another possible explanation is that time, as a performance measure, is not a sensitive measure in discriminating between performers in this particular motor task. There is also the possibility that participants were not required to practice enough to elicit performance differences. However, the result of the analysis on error performance indicated that all three groups improved from the pretest to the posttest, and that participants in the part practice group elicited the greatest improvement. Thus, it is unlikely that a lack of practice drove the time results.

EEG hemispheric differences

The performance outcome results suggest that learning did occur based on the errors data. This enabled us to further evaluate the results of the EEG portion regarding the psychophysiological processes that occurred. The results of our study support our first hypothesis. Results indicated a significant difference in the lower and upper alpha waveband with greater activity in the left hemisphere. This may be due to the fact that all participants were right handed and that muscle activation for the right hand is most active in the left hemisphere. This effect may have washed out any visuo-spatial driven hemispheric differences that would normally exist for this task [14]. The results of the current study do partially support past research conducted by Hatfield et al. [22] in which the researchers found hemispheric differences with an increase in alpha power in the left hemisphere and stability in the right hemisphere prior to the trigger pull of skilled marksmen in O1 and O2. Similarly, Rebert et al., [15] revealed that during a visualspatial task the performer engages the left hemisphere more as compared to the right for sites C3, C4, O1 and O2. Thus, the results from these studies provide support of our results concerning hemispheric lateralization.

EEG site differences

With regard to regional activation the results of this study indicated differences between the occipital and the central sites, and specifically that the occipital site had greater lower alpha power than did the central site during the mirror star tracer task. The results also indicated a significant interaction between test and site, with less alpha power from the pretest to the posttest. Greater alpha power was also observed in the central site during the posttest. In the upper alpha waveband, results indicated a significant difference between cortical activation in the occipital sites as compared to the central sites. Not surprisingly, these results evidence greater cognitive activity in the central sites than in the occipital sites during the mirror star tracer task. Past research has shown that lower alpha corresponds to less cognitive activity (e.g., relaxation), and that upper alpha reflects physiological activity associated with the stimulus perception [12]. The results from the current study demonstrate alpha power at the occipital sites in both the lower and upper alpha wavebands to be greater than the activity level at the central sites. Thus, cortical activity was greater in the pre motor cortex than in the visual cortex of the brain. These results are consistent with the results of Klimesch et al. [12], based on averaged event related desynchronizations over frontal, central, parietal, temporal and occipital sites, that showed upper alpha responds to cognitive processes and encoding of the stimulus (as a result of task novelty), and thus is more sensitive to stimulus specific processes while lower alpha may indicate a familiarization, or more efficient response, to the task. In this study, once the participants had practiced the skill using either method (i.e., whole or part practice), the physiological demand on the brain was minimized. It appears that the participants learned how to efficiently utilize visual information in the form of feedback from the mirror while tracing the star. A primary comparison study was that of Etnier et al. [3], who also used a mirror star tracer task to observe changes in EEG as participants learned the new task. The researchers measured performance using 8 second trials on a mirror star tracer while recording from 10 locations that included C3, C4, O1 and O2. The results indicated that as relatively permanent performance changes occurred due to learning, concomitant increases in EEG alpha also occurred, after 155 trials of practice. More specifically, they observed significant differences between occipital alpha power and central alpha power following practice of the mirror star tracer task, with occipital power significantly higher. These mimic our findings to some degree. We showed a change in lower alpha from pretest to posttest for all participants, irrespective of practice type. We also showed greater occipital power than central power across all four of our wavebands, again irrespective of practice group or pretest vs. posttest. This might indicate that all of our participants actually improved performance on the task (a fact made clear by the performance times for each group) and that perhaps our practice groups did not perform enough practice to improve beyond that which occurs due to task familiarization. In addition, the current results expand upon Etnier's results by demonstrating a parallel trend in the three additional wavebands (upper alpha and lower/upper beta). Perhaps most importantly, Etnier et al. [3] do not support our current findings that show a decrease in activity in the occipital site from the pretest to the posttest. The changes in alpha levels observed in our study were significant with regard to site, but there were no differences with regard to practice group. Aside from the possibilities raised earlier in the discussion, another possible explanation is the fact that the mirror tracer task is a novel task that is not suitable for examining whole/part practice methods. As Magill [2] states, individuals tend to learn motor skills that are high in complexity and low in organization most effectively by using the part method practice. It appears that the mirror star tracer task does not fit into this general rule, as it is a task that is low in both complexity and organization. Thus, it is suggested that the mirror tracer task may be too simple to gauge differences between practice methods.

Alpha vs. beta wavebands

The results of this study do not support our second hypothesis. Results indicated an increase in the lower and upper beta wavebands in the left hemisphere. It is difficult to compare these hemispheric results to past research due to the scarcity of literature regarding the use of beta power to measure learning. Klimesch et al. [12] and Marks and Isaac [13] have shown that lower beta is linked to sensory stimulation and upper beta is associated with high levels of arousal, based on data averaged over 16 EEG channels (including C3, C4, O1 and O2). In the current study, sensory stimulation would be needed to proficiency out during the mirror star tracer task. In fact, sensory stimulation would be present throughout the task based on the visuo-motor feedback obtained from the mirror. Kubitz and Mott [11] suggest that there is an inverse relation between alpha and beta waveforms with respect to the frontal and temporal areas (F3, F4, T3 and T4); however, Klimesch et al. [12] reported that when appropriately analyzing the alpha and beta frequency bands, there is a concomitant behavior between alpha and beta desynchronization. In this study, our results support the notion that alpha and beta display a simultaneous behavior.

In the present study, the results did not indicate learning differences; however, differences between the activity in the occipital and central sites for both upper and lower beta waveforms were present. This contradiction in the relation between alpha and beta wavebands has been documented in past research (J. Shaw, personal communication, February 26, 2000). As the participants in all groups performed on the mirror star tracer task, the alpha and beta levels presented a similar behavior. This relationship carried on throughout all four sites, as the occipital sites consistently had consistently larger amounts of activity in both the alpha and beta wavebands than did the central sites. The central sites had similar values throughout the four wavebands, with only minor deviations from the median score.

Applications to practice and training

With respect to neuromuscular training for injury prevention or rehabilitation, the current results provide implications for program design. Specific to injury prevention, there is emerging evidence that indicates neuromuscular training implemented at earlier ages is most effective in the reduction of traumatic knee injury [23]. It has been suggested that cognitive developmental considerations are also critical to optimize integrative neuromuscular training for youth [24]. Specifically it is required that instructors acknowledge and address the varying attentive abilities of young athletes [24]. For example, Hicks law describes that the more choices an individual has, the longer it takes to make a decision [25]. Neuromuscular and neurocognitive processing during skill training may cause an athlete to hesitate as they consider various performance options which is disruptive to the motor engrams needed to support optimal movement strategies. Understanding when alpha activity decreases can be indicative of a more relaxed, efficient performance. This may be facilitated through neuromuscular and skill training that integrates partial movement focus. This may be even more beneficial to youth with developing neurocognitive processing abilities and an early "training age" [24,26]. Moreover, feedback for youth that removes the external focus and employs a partial movement may support the acquisition of skill by removing the focus on task performance during complex sport related skills, or active challenges to attention [24].

Evidence from pilot data in our laboratory suggests that younger or new learners are often not prepared to adapt to complex training in the context of perceptual-motor or cognitive performance. Accordingly, they are likewise susceptible to distraction during complex sports related tasks. The preliminary data indicate that a more experienced athlete who has acquired a strong motor skill base may remain consistently focused on task performance and, thus, less susceptible to distractions (i.e., exhibit lower alpha activity). Based on the current data, further research is warranted to determine if the whole-part-whole method of learning is required to enhance learning and skill transfer in more elite athletes, and whether EEG can be a useful tool for identifying psychophysiological changes during the learning process [24,27]. Conversely, in youth Evidence from pilot data in our laboratory suggests that younger or new learners are often not prepared to adapt to complex training in the context of perceptual-motor or cognitive performance. Accordingly, they are likewise susceptible to distraction during complex sports related tasks. The preliminary data indicate that a more experienced athlete who has acquired a strong motor skill base may remain consistently focused on task performance and, thus, less susceptible to distractions (i.e., exhibit lower alpha activity). Based on the current data, further research is warranted to determine if the whole-part-whole method of learning is required to enhance learning and skill transfer in more elite athletes, and whether

EEG can be a useful tool for identifying psychophysiological changes during the learning process [24,27]. Conversely, in youth the current data indicate that it is prudent to utilize training strategies that account for the varying attentive abilities in new learners, and this may be supported by partial movement focus, to optimize training outcomes [24]. Therefore, simpler tasks, in undistracted scenarios may support program design in younger less skilled athlete to develop sound motor skills. Again, measuring EEG in this context may provide insights into the effectiveness of such strategies to overall performance.

In rehabilitation settings there may be a deficiency in the transition from an intense, internal attention focus during practice sessions to a more relaxed focus that enables adaptation to unexpected movement requirements for athletic activities on the field. Learning strategies without a partial movement focus have traditionally been utilized, but may be less suitable for the acquisition of the control of complex motor skills required for sport reintegration. The current data indicate that whole part whole training and instruction methods might support complex motor skill acquisition during rehabilitation and transition back into sport [28].

Limitations and future directions

Several limitations need to be addressed. As has already been discussed, participants may not have practiced enough to alter performance. In addition, the absence of a retention trial makes it difficult to explicitly state that learning occurred, although the observed changes in the lower alpha waveband support the notion that a more relaxed, efficient performance was achieved. It should also be noted that, because all groups performed the mirror star tracer task, conclusions drawn from the current link between EEG activity and the mirror star tracer task (believed to be a high visuo-spatial task) are speculative. More research is needed to elucidate this relation. Future research should also examine different practice methods, along with increasing the ratio of testing and practice in order to determine how many trials individuals need before learning occurs and to determine if age or stage of rehabilitation can have an effect on these parameters. A greater number of practice trials would ultimately allow a greater differentiation between the practice and control groups. Further, an increase in spatial resolution would allow scientists to use other signal processing techniques such as source derivation. Perhaps most importantly, linking changes due to learning to permanent changes in EEG activity during baseline resting periods, and retention periods would also help to identify successful implementation of training and rehabilitation protocols.

Conclusions

Similar to the conclusions made by Klimesch et al. [12], our results demonstrate a strong relation between the hemispheric lateralization of the alpha and beta waveforms. Our data also support previous work on the lower alpha activity at the central and occipital sites by Etnier et al., and expands on their results by demonstrating concomitant activity in an additional three wavebands (upper alpha and upper/lower beta). Lower-alpha differences from pretest to posttest were also observed for all three groups. It is possible that a familiarization period was enough to acclimate the participants to utilizing the mirrored visual feedback. Further, it can be presumed that feedback is prevalent throughout the duration of the task, although not utilized efficiently until after the participants gain proficiency in the motor task. Once the participants become proficient, they may be able to use constant feedback more efficiently which in turn will result in improved performance. Ultimately, the next step is to examine the effects of brain adaptation to more complex neuromuscular training tasks.

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