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Identification of Beta Oscillatory Patterns During a Hand Grip Motor Task: A Comparative Analysis pre- and post-Exercise

Xuanteng Yan, Georgios D. Mitsis, *Senior Member, IEEE,* Marie-Hélène Boudrias

Abstract— **Electroencephalography (EEG) based Movement-Related Beta Band Desynchronization (MRBD) within the beta frequency band (13 – 30Hz) is commonly observed during motor task execution, and it has been associated with motor task performance. More recently, transient burst-like events termed *beta bursts* have been identified as another potential biomarker of motor function. Previous studies have reported decreased MRBD magnitude induced by exercise. However, little is known in terms of the effects of high-intensity exercise on beta burst patterns. In the present work, we investigated the modulatory effects of exercise on different beta burst features prior to, during and post motor task execution. We found that exercise mainly affected burst duration and burst rate within the left motor cortex area (M1) that is contralateral to the moving hand. Meanwhile, burst amplitude in the contralateral M1 area was affected differently by exercise, with smaller burst amplitude values observed during the movement preparation phase and larger magnitude during as well as post motor task execution. Since MRBD and beta burst patterns are closely associated with motor task performance, results from the present study can promote understanding about the association between exercise induced neural plasticity changes and motor performance, which can be further used for designing a subject-specific training therapy for improving motor function.**

I. Introduction

Electroencephalography (EEG) is a non-invasive technology for monitoring electrical activity of brain cells. With the use of EEG, it has been observed that there is decrease in the EEG signal spectral power within the beta frequency band (13–30Hz) during motor task execution. This decrease is termed Movement-Related Beta band Desynchronization (MRBD) [1]. Recent studies have also reported that the trial averaged beta band power is dependent on beta bursts, which are defined as transient burst-like events within the beta frequency band [2]. Further, both MRBD and beta bursts have been found to be associated with motor performance [3], [4].

Previous studies have shown that a bout of high-intensity exercise can modulate neural plasticity, affect underlying brain oscillatory patterns such as MRBD, while also enhancing motor learning [5], [6]. However, it is still unclear how exercise affects beta band activity, especially beta bursts. In this context, here we investigate the impact of exercise on beta burst activity using EEG. We found that exercise had a differential impact on beta bursts during different phases of handgrip execution. Specifically, exercise induced higher burst rates in the contralateral motor cortex (M1) area during the movement preparation phase while lower burst rates during and after motor task execution. Furthermore, beta bursts tended to be of longer duration and larger amplitude in the post-movement phase after taking exercise. As beta oscillations are associated with motor function, our results offer insights into exercise induced brain wave and neural plasticity changes that could be applied to the design of personalized rehabilitation strategies.

X. Yan is with the Graduate Program in Biological and Biomedical Engineering, McGill University, Montréal, Canada.
G. D. Mitsis is with the Department of Bioengineering, McGill University, Montréal, Canada.
M-H Boudrias is with the School of Physical & Occupational Therapy, McGill University, Montréal, Canada.

II. Methods

A. Participants

Twenty-four healthy, young (aged 19-33 years) and right-handed adults were recruited in this study. Participants were excluded from participation if they were taking any medicine that could affect their central nervous system or learning ability. This experiment was approved by the local ethics committee (CRIR-1134-0116). All participants signed a written informed consent form and received money compensation for their participation.

B. Experimental Paradigm

The experimental data used for the current study comes from the study reported in Dal Maso et al. [5]. Briefly, the experiment was comprised of two sessions. In the first session, participants performed a graded exercise test (GXT) while cycling on an ergometer bike (Figure 1A), during which their maximum oxygen consumption (VO_{2peak}) was measured to assess each participant's general fitness level. Subsequently, subjects were randomly divided into an exercise (EXE) or a control (CON) group balanced in terms of age, gender, fitness level and body mass index. In the following session, participants initially rested for 5 minutes and baseline EEG signals were obtained. Then, all subjects performed 50 trials of the handgrip task by squeezing a gripper to 15% of their maximum voluntary contraction (MVC) forces for 3.5s using their dominant hand, followed by a random inter-trial resting period of 3~5s. Following this, subjects in the EXE group underwent 17-min of high intensity exercise training on the bike. The training included a 2-min low-speed cycling as a warm up, followed by three blocks of exercise, with each block containing a 3-min high-speed cycling to increase heart rate and sequentially a 2-min low-speed cycling to recover (Figure 1B). All participants repeated 50 trials of the handgrip 30, 60 and 90 minutes after the exercise/rest session. Since we would like to investigate the long-lasting effects of exercise, results corresponding to data collected at 90 minutes are only reported in the present study.

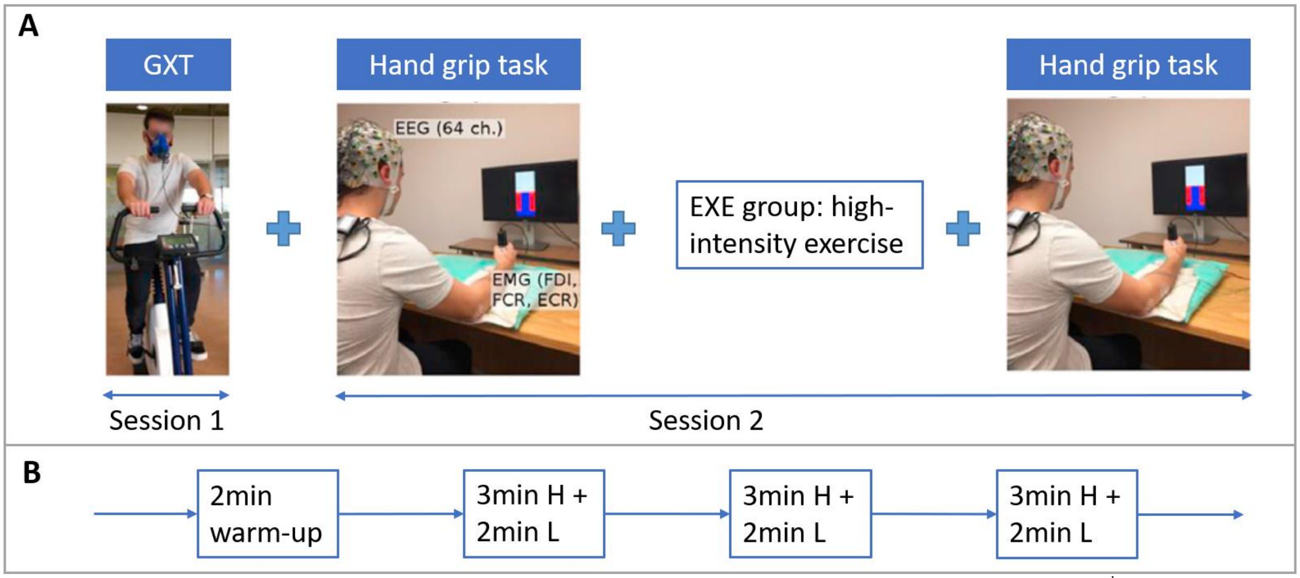

Figure 1. (A) Experimental paradigm. Participants performed the GXT to obtain their fitness level during the first session. The 2nd session took place at least 2 days after the initial session to avoid any lasting effect of GXT. (B) Flowchart of the high intensity training. The training consisted of a warm-up of low-speed cycling for 2 min followed by 3 blocks of training, with each block comprised of a 3min high-speed (H) cycling followed by a 2 min low-speed (L) cycling (Figure adapted from Dal Maso et al.[5]).

C. EEG data acquisition and processing

A 64-channel EEG system (BrainVision) was used to record brain oscillatory patterns during handgrips. The EEG data were band-pass filtered within 13–30Hz with a Kaiser window FIR filter for extracting brain oscillations within the beta frequency band. The collected EEG signals from eight channels that covered both contralateral and ipsilateral M1 areas were used for further analysis, namely electrodes C3, C4, CP1, CP2, C1, C2, CP3 and CP4. The EEG recordings from each trial were categorized into three different phases according to the visual cue that denotes the onset of motor task. Specifically, we define the movement preparation (pre-mov) phase as the 1s period prior to the appearance of visual cue, the ongoing movement (moving) phase as the time interval from 0.5 to 3.5s after the appearance of the visual cue, and the post movement (post-mov) phase as the time period 0.5 to 1s after the termination of the task, which corresponds to 4 to 4.5s after the appearance of the visual cue.

To extract the MRBD patterns during the motor task, we first computed the average beta band power during the 5 min resting state as the reference baseline. MRBD was obtained by calculating the power difference between resting state and ongoing movement, normalized by the resting state baseline power:

$$MRBD\% = \frac{\beta_{base} - \beta_{0.5\sim3.5}}{\beta_{base}} \times 100\% \quad (1)$$

In this equation, β_{base} represents the baseline beta band power during the 5 min resting state. $\beta_{a\sim b}$ represents the beta band power between time a and time b.

The method we used for extracting beta burst was adapted from Sporn et al., Tinkhauser et al. and He et al. [7]–[9]. Firstly, EEG data during the hand grip motor task were resampled at 500 Hz and band-pass filtered within the beta frequency band after removing the DC offset using a Kaiser window FIR filter. Then we extracted the envelope of EEG signals using the Hilbert transform. Because the average beta band power changes during the motor task, we defined different thresholds corresponding to different phases of the motor task for detecting beta bursts. As shown in Figure 2, the

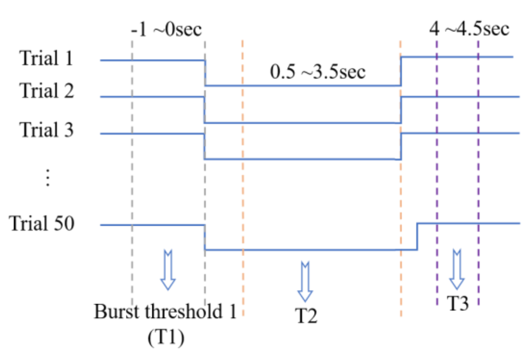

Figure 2. Procedure for defining beta bursts. Each horizontal line is an illustrative demonstration of beta band power for each trial. The burst threshold was defined separately for each movement phase by averaging the signal envelope over 50 trials and using the 75% value of the mean envelope as the threshold for detecting beta bursts.

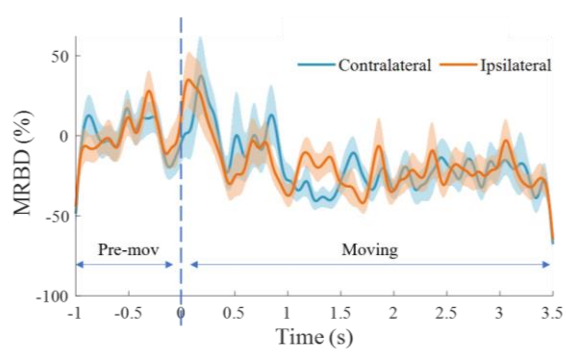

Figure 3. Demonstration of MRBD patterns in the contralateral (blue) and ipsilateral (orange) hemisphere during the hand grip motor task. Time zero denotes the time point when the visual cue representing the onset of motor task appears.

burst threshold was set at 75% of the average amplitude of the signal envelope during each phase, and beta bursts were defined as the signal segments with an amplitude above this pre-determined threshold and a duration longer than 33ms, which is the minimum length of a beta wave (30Hz). The beta burst features investigated in the present study were burst rate, burst duration and burst amplitude.

D. Statistical analysis

Since the objective was to investigate the effect of exercise on beta burst patterns, we compared group means of the aforementioned beta burst features before and after exercise using paired t-tests. The significance level was set to a level α equal to 0.05. Bonferroni correction was applied if multiple comparisons were involved.

III. Results

A. MRBD and Beta Burst Patterns During Motor Task

The averaged MRBD magnitude across participants in the EXE group is demonstrated in Figure 3, in which the time point zero denotes the onset of motor task. It can be seen that after the onset of the motor task, there was a decrease in the beta band power within both the contralateral and ipsilateral M1 areas. This is consistent with previous related studies [10], [11].

B. Effect of Exercise on MRBD and Beta Burst

To assess the effect of exercise on MRBD, we computed the MRBD magnitude in the EXE group before and after exercise. Results in Figure 4A show that after completing the high-intensity workout, these subjects exhibited a significantly decreased MRBD magnitude in all channels covering both contralateral and ipsilateral M1 areas. This result is consistent with previous studies showing that exercise induces a smaller decrease in beta band power while performing handgrips [12]. Moreover, Figure 4B shows that the contralateral M1 area exhibited a more pronounced beta band power decrease compared to the ipsilateral hemisphere, and the difference in MRBD across hemispheres became larger after exercise.

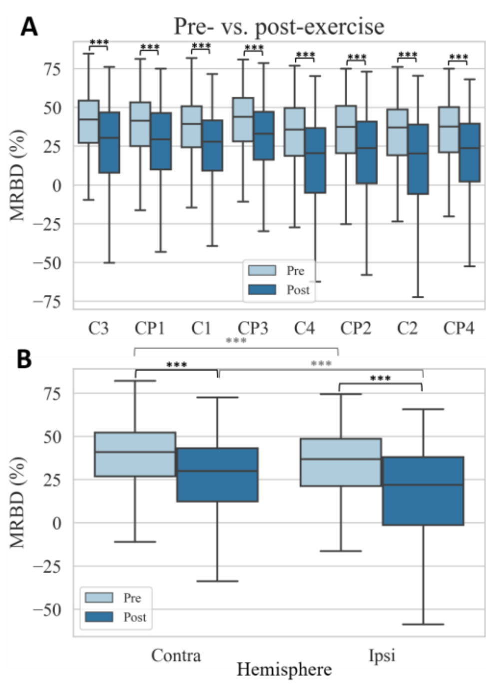

Figure 4. MRBD magnitude in the EXE group pre- (light blue) and post-exercise (dark blue). (A) MRBD magnitude in different channels. (B) Grouped MRBD within different hemisphere. (*: $p < 0.05$, **: $p < 0.005$, ***: $p < 0.001$).

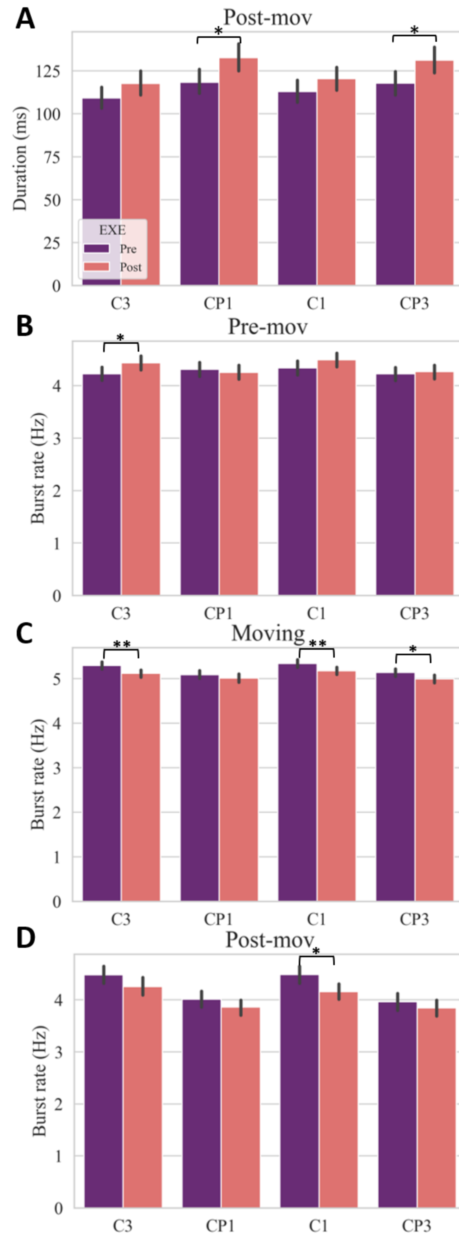

Figure 5. Burst duration and burst rate during different phases of motor task execution before and after exercise from the EXE group. (A) Burst duration in post-mov phase. (B) – (D) Burst rate in the pre-mov phase (B), moving phase (C) and post-move phase (D). (*: $p < 0.05$, **: $p < 0.005$, ***: $p < 0.001$).

We further examined the effect of exercise on beta burst patterns in the EXE group. To achieve this, burst features were compared separately during the pre-mov phase, moving phase and post-mov phase. Results in Figure 5A show that exercise mainly affected burst duration in the post-mov phase, with electrodes CP1 and CP3 demonstrating longer burst durations

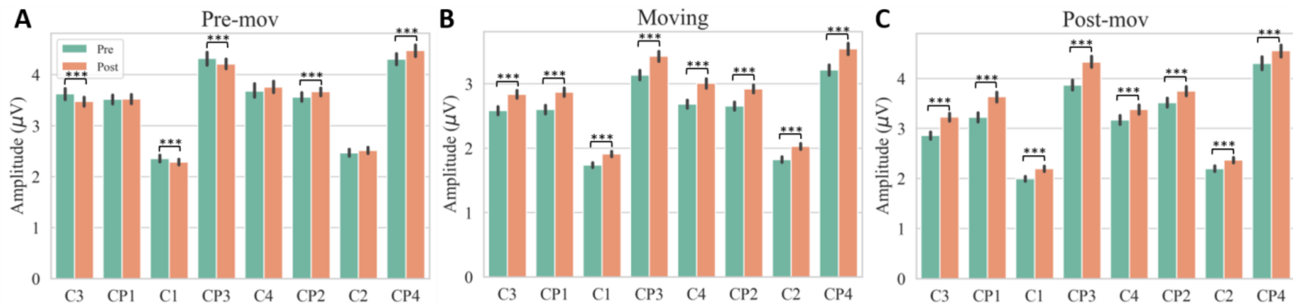

Figure 6. Amplitude of beta burst pre- (green) and post-exercise (orange) in the pre-mov (A), moving (B) and post-mov (C) phase from the EXE group. (*: $p < 0.05$, **: $p < 0.005$, ***: $p < 0.001$).

after exercise. Moreover, exercise had distinct impacts on the burst rate during different phases of movement. Specifically, more beta bursts were generated during the pre-mov phase (Figure 5B) while burst rate decreased during both the moving and post-mov phase after exercise (Figure 5C & D).

We found that burst amplitude during the pre-mov phase exhibited different patterns of change: specifically, bursts within the contralateral M1 area decreased in amplitude, while beta bursts within the ipsilateral M1 area became larger in amplitude (Figure 6A). Furthermore, a significant increase in burst amplitude was found in all electrodes during the moving and post-mov phases (Figure 6B & C), suggesting that high-intensity exercise can enlarger burst amplitude during motor task execution, which can further contribute to the reduced MRBD magnitude.

IV. Discussion

In the present work, we investigated how beta oscillatory patterns during different phases of a motor task were influenced after taking a bout of high intensity exercise. We showed that high-intensity workout mainly affected burst duration and rate within the contralateral M1 area. Furthermore, subjects exhibited a relatively smaller MRBD magnitude after exercise, which was accompanied by a larger burst amplitude during movement and post movement period.

Previous studies have shown that a single bout of acute exercise can improve functional connectivity and increase motor cortex excitability, thus contributing to better motor memory consolidation and skill retention [13], [14]. It was also found that a smaller MRBD magnitude is associated with improved motor performance [11]. Our results are consistent with previous findings, as we detected smaller MRBD magnitude after acute exercise. Moreover, we found an exercise-induced reduced burst rate during movement. Since beta bursts are transient events of particularly high power indicating excitatory neural firing patterns, lower burst rates may imply less brain resources being recruited during motor task execution, which in turn suggests a more efficient recruitment of brain resources and consequently a smaller MRBD magnitude induced by exercise [15]. Thus, these results imply that beta burst can be used as a guidance to design subject-specific training strategy for enhancing motor function.

Acknowledgment

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