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Cortical networks underlying coordinated movements revealed by magnetoencephalographic beamforming

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Abstract. Event-related beamformer analyses was applied to magnetoencephalographic data from five subjects who performed synchronized and syncopated unimanual motor coordination tasks at rates ranging from 1.25 to 1.75Hz. For syncopation, the stability of the coordination pattern decreased systematically with increasing movement rate. Averaged sensor data revealed the motor field (MF) and motor evoked fields (MEF) I and II. Additionally, we observed an early field (M0) at approximately 160ms prior to peak flexion with polarity opposite to the MF. Beamformer analysis reproduced previous findings that showed the MF activity being generated mainly in precentral gyrus and the activity of the MEFs is distributed across multiple generators in pre and post-central gyrus. For syncopation, additional areas of activation were observed during early M0 and late MEF II time periods which included premotor, frontal, cingulate, and SMA, with the premotor areas exhibiting a dependence on rate. These results provide evidence of the power of MEG beamforming for characterizing the properties of cortical neural activity at a high resolution in space and time.

Keywords: Magnetoencephalography, Beamforming, Motor Coordination, Synchronize, Syncopate

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1. Introduction

Unimanual sensorimotor coordination with an external metronome is stable for synchronization (on-beat) and syncopation (between-beat) tasks when performed at low movement rates. However, under parametric increase in rate, the syncopation pattern becomes progressively destabilized until at some critical frequency subjects switch spontaneously to the synchronized coordination pattern. The inability of syncopating at higher rates has been attributed to attentional and timing related demands required for

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successful performance [1,2]. As such, these tasks reflect functional couplings between perception and action in the human nervous system. Currently there exists no single non-invasive imaging method that provides both the temporal and spatial resolution necessary to fully quantify related spatiotemporal dynamics at the level of the brain.

Recently however, spatial filtering methods for magnetoencephalography (MEG) analysis have been used successfully to localize the sources of event-related and induced brain activity and to track the time course of such activity with a temporal resolution of milliseconds and spatial resolution of millimeters [3,4]. Here, we applied event-related synthetic aperture magnetometry (ER-SAM) beamforming methods to MEG data recorded from subjects performing synchronized and syncopated unimanual coordination tasks at different rates.

2. Methods

MEG was recorded using a whole-head Omega 151 magnetometer (VSM MedTech, Ltd. Coquitlam, BC) from 5 subjects (1 female, aged 23-45) as they preformed synchronized and syncopated coordination with an auditory metronome at rates ranging from 0.75Hz to 1.75Hz. Rhythmic motor-only conditions across rate were also performed. Tasks consisted of pressing a small air pillow located beneath the subjects' right index finger and movement profiles were recorded as pressure changes detected by a transducer located outside the magnetically shielded room. MEG data was sampled at a rate of 1250Hz, filtered 0.1-400Hz, and epoched in windows of 400ms centered around peak flexion leading to about 200 epochs per subject and condition that were used for further analysis. Sensor space was coregistered to the subjects' T1 weighted MRIs. ER-SAM analysis [3] was performed on the epoched data, normalized to standard brain space, and thresholded at a level of 60% of maximum activation. Virtual sensor time series were obtained from locations indicated by peaks in the ER-SAM images.

3. Results

A grand average of the MEG data from the motor-only condition (Fig. 1) clearly shows the well known peaks for the motor field (MF) prior to peak flexion and the motor evoked fields I and II at later times. In addition, a fourth peak (M0), most likely related to the rhythmic nature of the task, is evident just prior to movement onset.

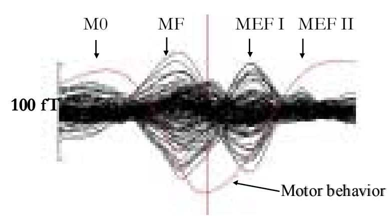

Fig. 1. Butterfly plot of a grand average from the motor-only condition exhibiting four peaks of activity shown together with the average response profile.

Results from an event-related beamformer analysis at the latencies of the peaks is shown in Fig. 2. Similarities can be observed in contra-lateral sensorimotor cortex for the motor-only and synchronization conditions, whereas in the syncopation condition more focal activity in sensorimotor cortices is evident as are additional areas of activity in ipsi-lateral sensorimotor cortex, premotor (SMA), and cingulate (not shown).

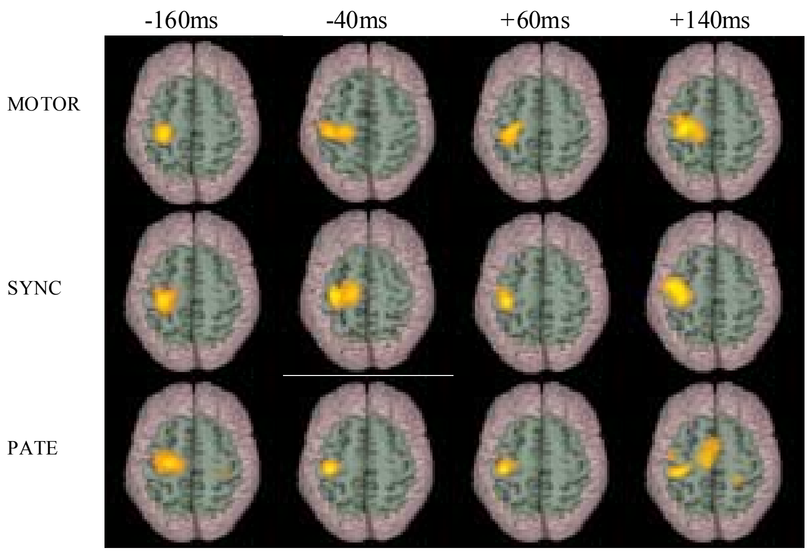

Fig. 2. ER-SAM source localization for the motor-only (MOTOR), synchronization (SYNC) and syncopation (PATE) conditions at latencies corresponding to the peaks in the grand averaged MEG waveforms.

Local activity in sensori- and premotor areas was calculated for the different rates using virtual sensors and is shown in Fig. 3. In sensorimotor cortex the MEF II is pronounced only for the slowest rate and diminishes when the movement gets faster. The MF prior to peak flexion decreases in the premotor area with increasing rate.

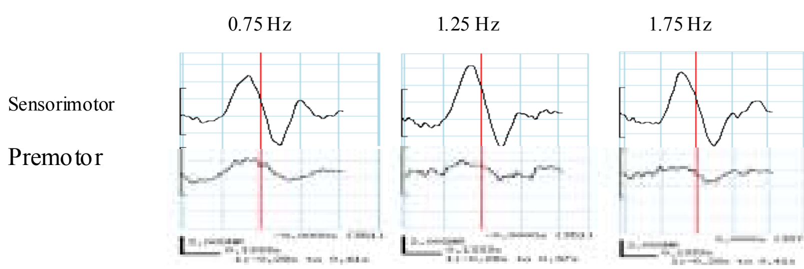

Fig. 3: Virtual Sensor time-series from 2 locations in a single subject for the syncopation condition across increasing coordination rate.

Induced activity in the premotor area (corresponding to the bottom row in Fig.3) is shown as time-frequency plots across rates in Fig. 4. In the high β-band the activity around peak flexion decreases with increasing rate (event related desynchronization). Conversely, a peak of coherent activity appears in the same frequency band at a latency of 0.2s (event related synchronization). In the α-band, activity becomes more organized around peak flexion with increasing rate.

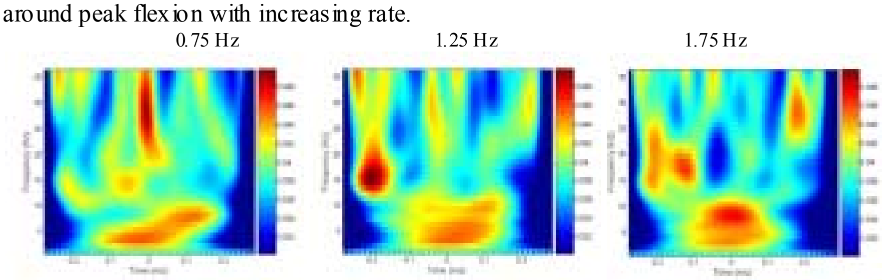

Fig. 4: Time-frequency plots for the premotor virtual sensor from a single subject for the syncopation condition across rate.

3. Conclusions

Event-related beamforming techniques were applied to MEG data in order to characterize the spatiotemporal properties of brain activity during various motor coordination tasks known to exhibit behavioral dependencies on rate. Our findings are in agreement with previous fMRI studies on this subject as far as active regions are concerned. However, in contrast to fMRI our beamforming analysis allows us to determine the time course of neural activity in these regions on a scale of milliseconds. The results presented here demonstrate the power of beamforming as a research technique for non-invasive investigations of the relation between brain and behavior in humans. For example, this tool permits the study of coherence not only between electrodes or sensors outside the head, but between actual regions inside the brain, thereby identifying the functional connections between such regions and more generally the connectivity of the underlying network architecture.

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References

[1] K.J. Jantzen, F.L Steinberg, J.A.S. Kelso, Brain networks underlying human timing behavior are influenced by prior context. Proc Natl Acad Sci U S A. 2004; 101(17):6815-20.

[2] J.M. Mayville, K.J. Jantzen, A. Fuchs, F.L. Steinberg, J.A.S. Kelso, Cortical and Subcortical Networks underlying syncopated and synchronized coordination revealed using fMRI. Hum Brain Mapping. 2002; 17:214-29.

[3] D. Cheyne, L. Bakhtazad, W. Gaetz, Spatiotemporal mapping of the cortical activity accompanying voluntary movements using an event-related beamforming approach. Hum. Brain Mapp. 2006; 27:213-29.

[4] J. Vrba, S.E. Robinson, Signal processing in magnetoencephalography, Methods (Duluth) 2001; 25:249-71.