Event-Related Changes in Neuromagnetic Activity associated with Syncopation and Synchronization Timing Tasks

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Scope

- The investigation of the spatiotemporal dynamics of MEG activity during a sensorimotor coordination task:

finger flexion with an external metronome

- To understand why syncopation becomes unstable.

- To couple the behavioral response (shift in timing) with the reorganization of the dominant pattern in neuromagnetic activity.

- The decomposition of event-related fields into component auditory and motor brain responses and the study of possible interactions between them.

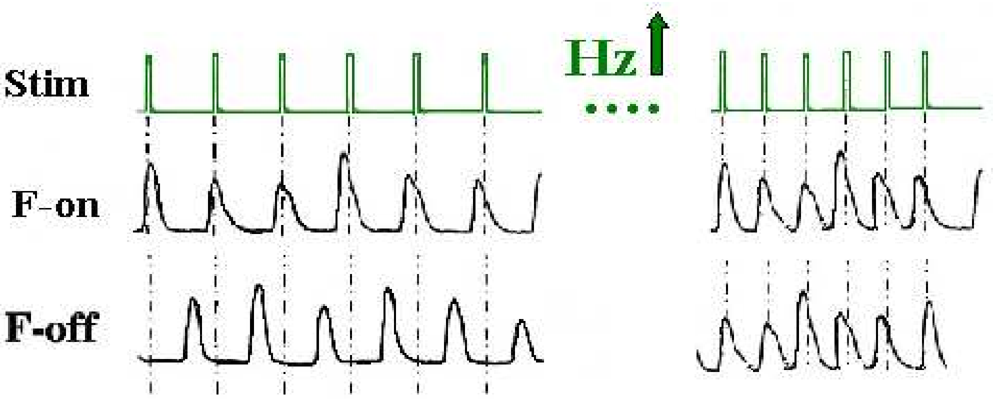
Outline/Introduction

➲ relation of brain activity with the finger motion

(Kelso et al.: ***Nature***,1998, ***NeuroImage,*** 2000 , etc)

“ *The brain does indeed generate signals that reproduce the actual movement trajectory (independent of the direction)* ”

➲ ***Experimental Observations* :**



synchronization (on-the-beat) is an easy task in the range [~0.6 - 4 Hz]
syncopation (off-the-beat) feasible in the lower rhythmic rates [<2 Hz]

The lack of a biomechanical explanation, points out the possibility that the perception of the metronome is coupled to the motor response

➲ ***Spatiotemporal Dynamics*** ***(*** *Haken’s approach* ***)****:*

- *phenomenological study* of the multidimensional MEG time series for describing the interaction between the auditory and motor response.

- exploitation of ***phase transition***.

➲ **Large-scale reorganization of neuronal activity:**

the role of Mu (8-12 Hz), beta (15-30 Hz), gamma (30-50 Hz) ranges.
event-related desynchronization (ERD)**.**

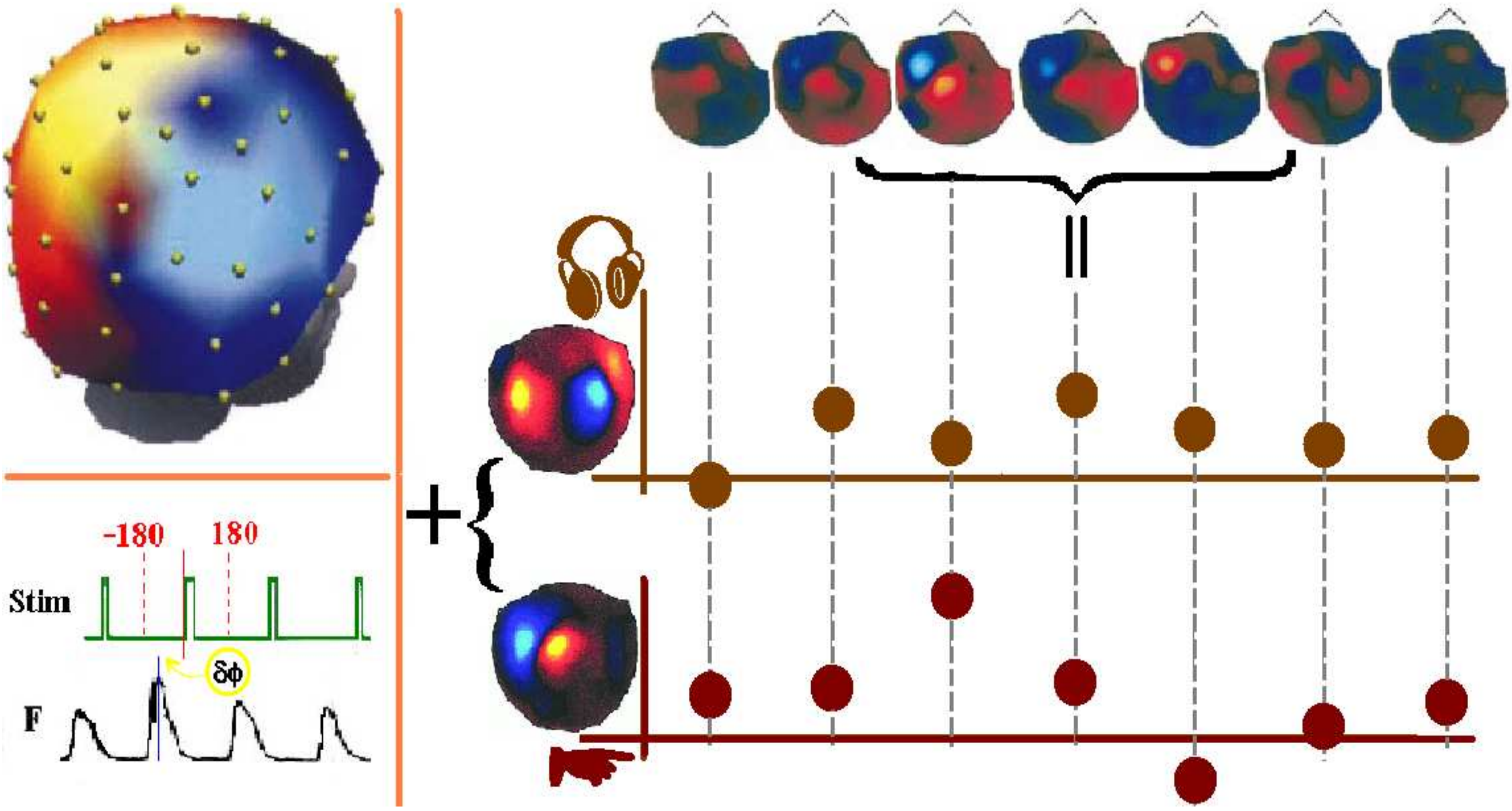
Haken's approach

Brain is treated as ***complex system*** that is probed at a macroscopic level:

The Concepts of ***self-organization*** and ***pattern formation*** are employed using the language of coupled non-linear dynamics to describe how the patterns of coordinated activity arise and evolve in time.

The notion of a "***collective variable***"
Observable *order-parameter* vs. *enslaved parameters*.

Probing the coupling between subsystems through the study of a ***Phase Transition.***



Event-related (de)synchronization

"An internally or externally paced event results not only in the generation of an event-related potential (ERP) but also in **a change in the ongoing EEG/MEG in form of an ERD/ERS**" [Pfurtscheller & L.da Silva, 1999].

These changes are time-locked to the event, but not phase-locked
and hence undetectable by averaging in the time domain.
They can be detected as frequency specific changes in terms of power and
they are considered to be due to ***a decrease or an increase in synchrony*** of the underlying populations

Both ***mu*** (8-12 Hz) and ***beta*** (15-30 Hz) rhythms show a decrease in power before movement over contralateral sensorimotor and midline premotor areas
as well as during movement bilaterally.

This ERD is thought to reflect a shift from "idling" to task related activity in underlying thalamocortical and corticortical networks.

The more complex the movement task
the greater the ERD in *mu* and *beta* activity.

On the contrary,
ERS was observed in *gamma* activity during drawing tasks.

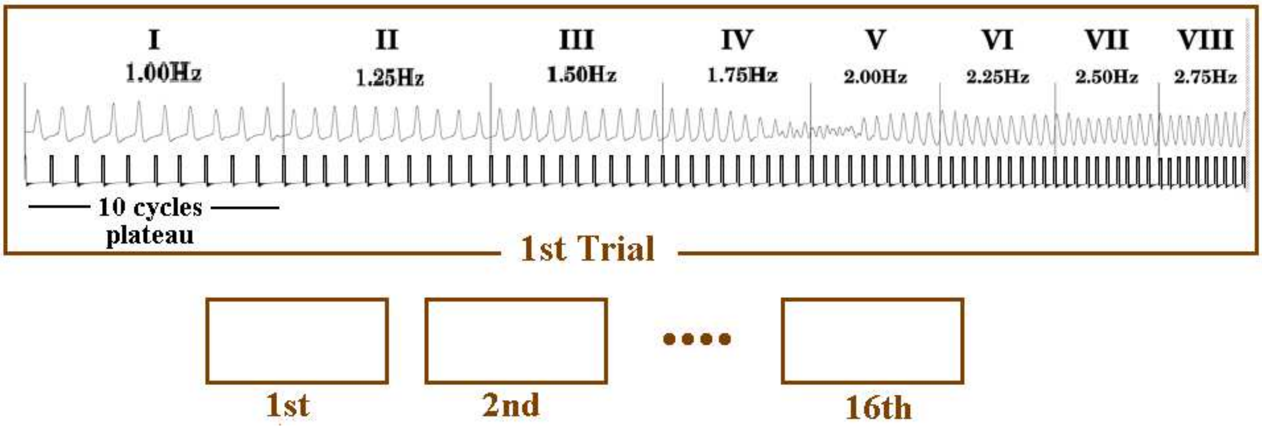
Both effects were stronger over contralateral sensorimotor areas.

Here, ERD is studied by means of a contrast between two conditions,
due to the lack of a "true baseline period"

METHODS

Task conditions:

Two auditory-motor coordination conditions : syncopation / synchronization



Two control conditions: auditory / motor

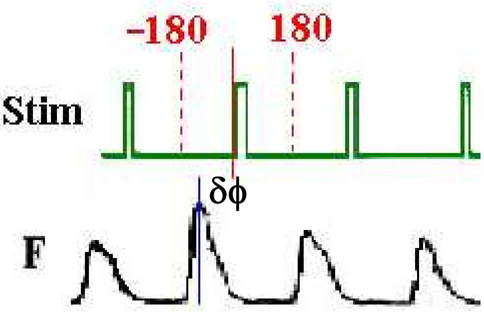
80 tones: randomized intervals of 2-4 sec / 80 self paced flexion mov.: 2-4 sec

Data

- 2 males/ 1 female, [27-41yrs], right-handed
- finger displacement as pressure changes in an air cushion
- brain activity using 143-ch. CTF system / at SF of 312.5 HZ / BW: [0.3-80Hz]
- auditory metronome: sound was delivered binaurally

Behavioral analysis

Metronome and response (finger movement) signals were used to determine the timing relationship on a cycle-by-cycle basis.



According to Relative Phase ,
the movements were classified as

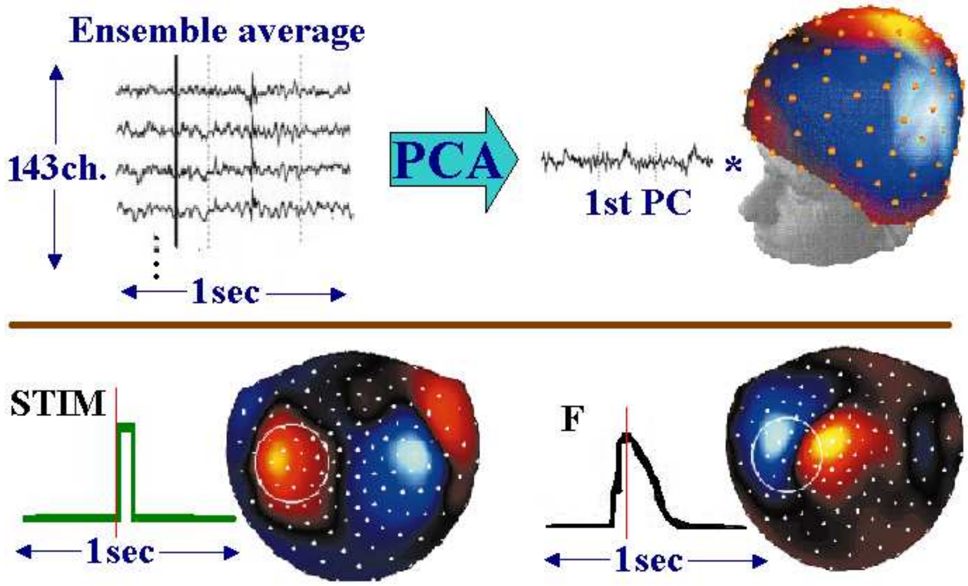
syncopated coordination : $\delta\phi = 180^o \pm 60^o$

synchronized coordination : $\delta\phi = 0^o \pm 60^o$

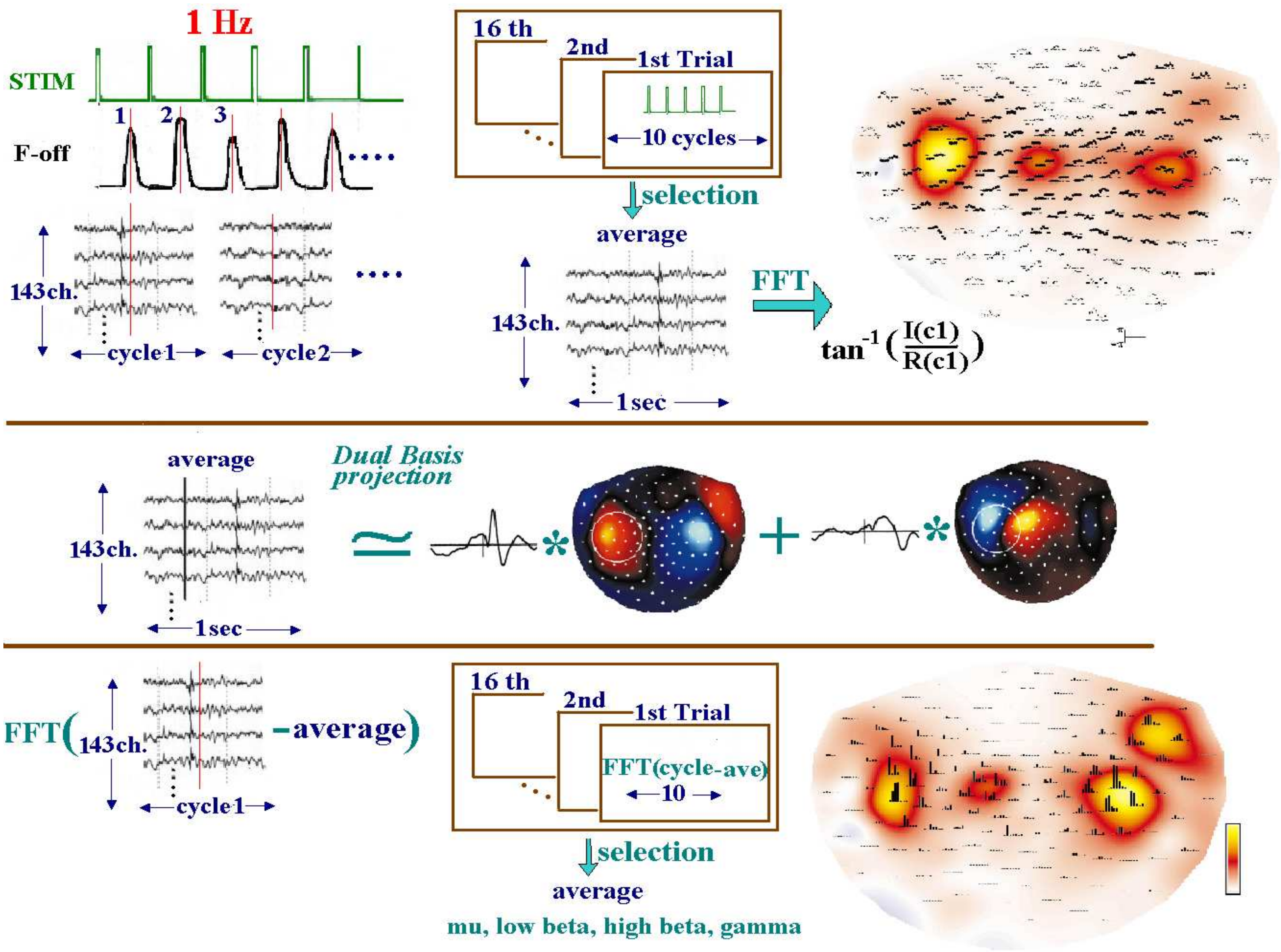
and “others” that excluded from further analysis.

MEG analysis: control conditions

➲ computation of the **primary field pattern** evoked by either an auditory tone or flexion event for each subject.



MEG analysis: coordination conditions



RESULTS

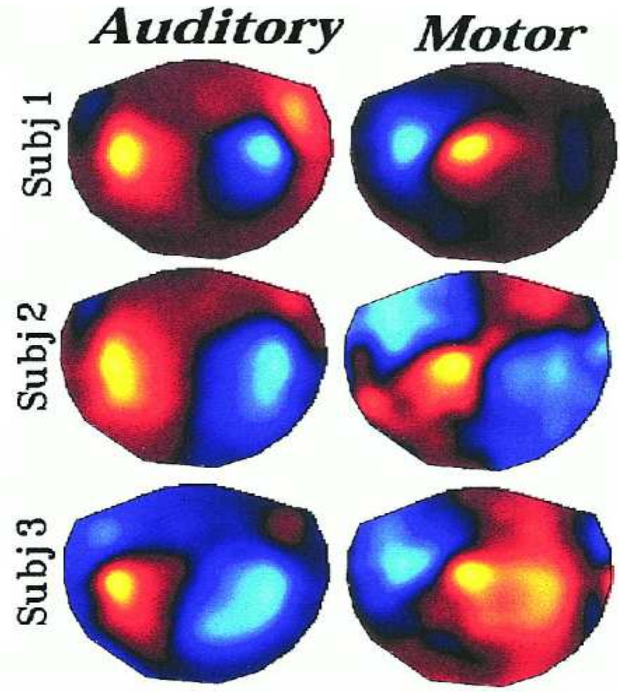
Task performance

TABLE I. Average relative phase (±SD) between peak response and tone onset*

	1.0 Hz	1.25 Hz	1.5 Hz	1.75 Hz	2.0 Hz	2.25 Hz	2.5 Hz	2.75 Hz
Syncopate condition								
S1	**143.2 (19.3)**	**153.7 (17.1)**	**164.0 (18.4)**	**189.7 (21.9)**	25.6 (24.6)	34.2 (13.9)	34.0 (14.6)	24.5 (20.8)
S2	**152.5 (27.8)**	**161.7 (33.5)**	**164.8 (30.0)**	**184.1 (30.2)**	**200.5 (27.7)**	− 1.2 (28.8)	8.5 (27.4)	30.3 (19.0)
S3	**160.0 (23.4)**	**164.0 (26.1)**	**184.1 (20.5)**	**202.3 (19.3)**	**205.4 (20.2)**	− 9.9 (31.5)	1.4 (28.5)	− 3.7 (28.1)
Synchronize Condition								
S1	10.0 (19.3)	2.3 (19.8)	2.8 (20.6)	7.3 (19.9)	10.7 (20.3)	11.7 (22.1)	17.7 (21.7)	13.5 (23.8)
S2	− 6.5 (18.3)	− 1.5 (23.8)	3.7 (22.7)	10.0 (23.8)	19.4 (17.9)	25.9 (18.3)	34.6 (15.9)	41.6 (11.9)
S3	2.8 (18.6)	− 7.5 (17.0)	− 13.3 (21.7)	− 14.2 (23.8)	− 3.7 (26.2)	− 3.4 (26.6)	− 0.7 (25.8)	− 1.4 (28.0)

Only for low metronome rates syncopation was feasible.
Transition to synchronization in high rates.

Control conditions: dominant patterns of activity



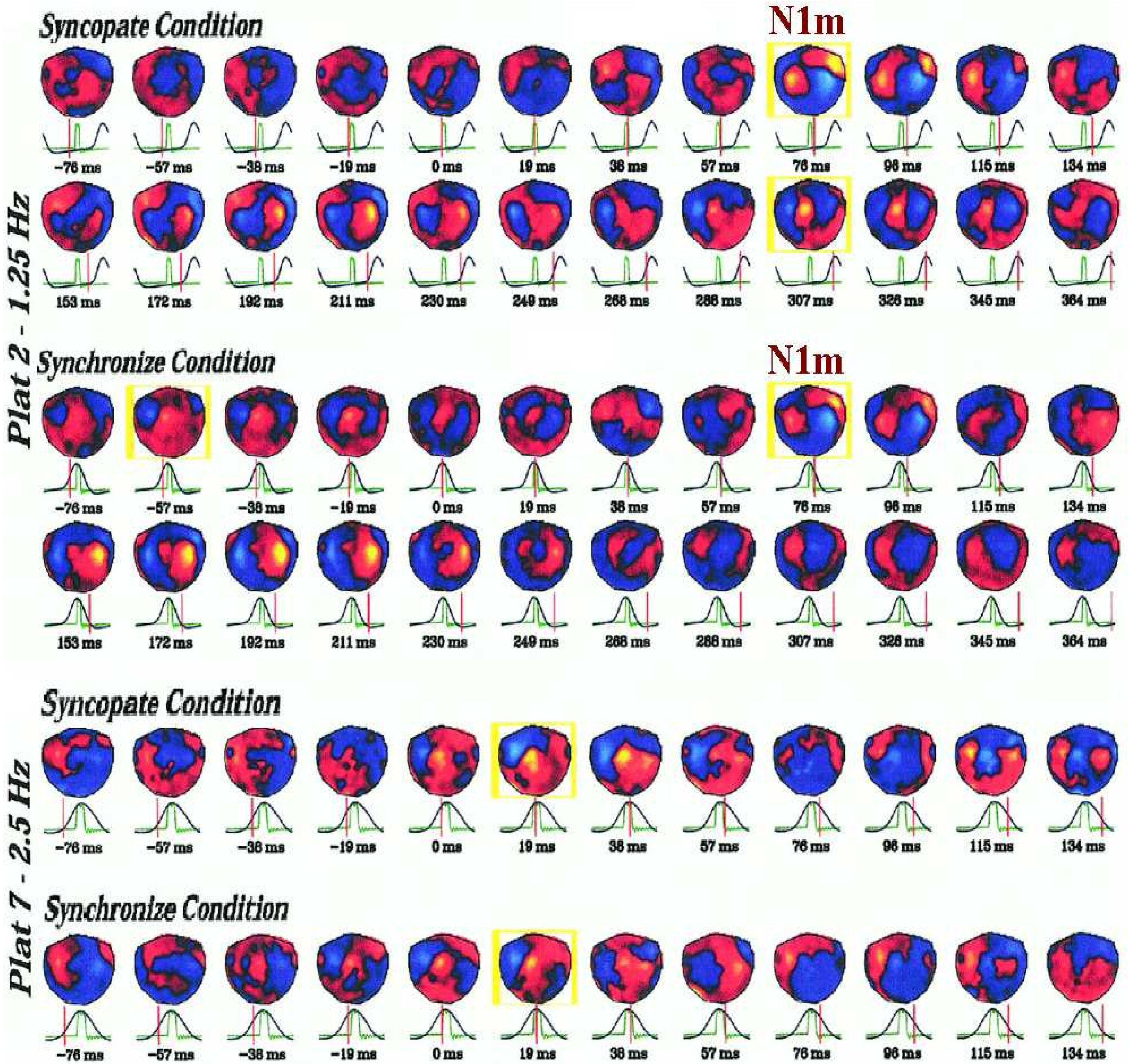
The auditory –related fields show bipolar activity bilaterally: reflecting activation of the primary auditory cortex in each hemisphere.

Motor-related patterns show single dipolar structure in the left central region, reflecting activation of the sensorimotor area (SM1) associated with movement of the right index finger.

Coordination conditions: event related fields

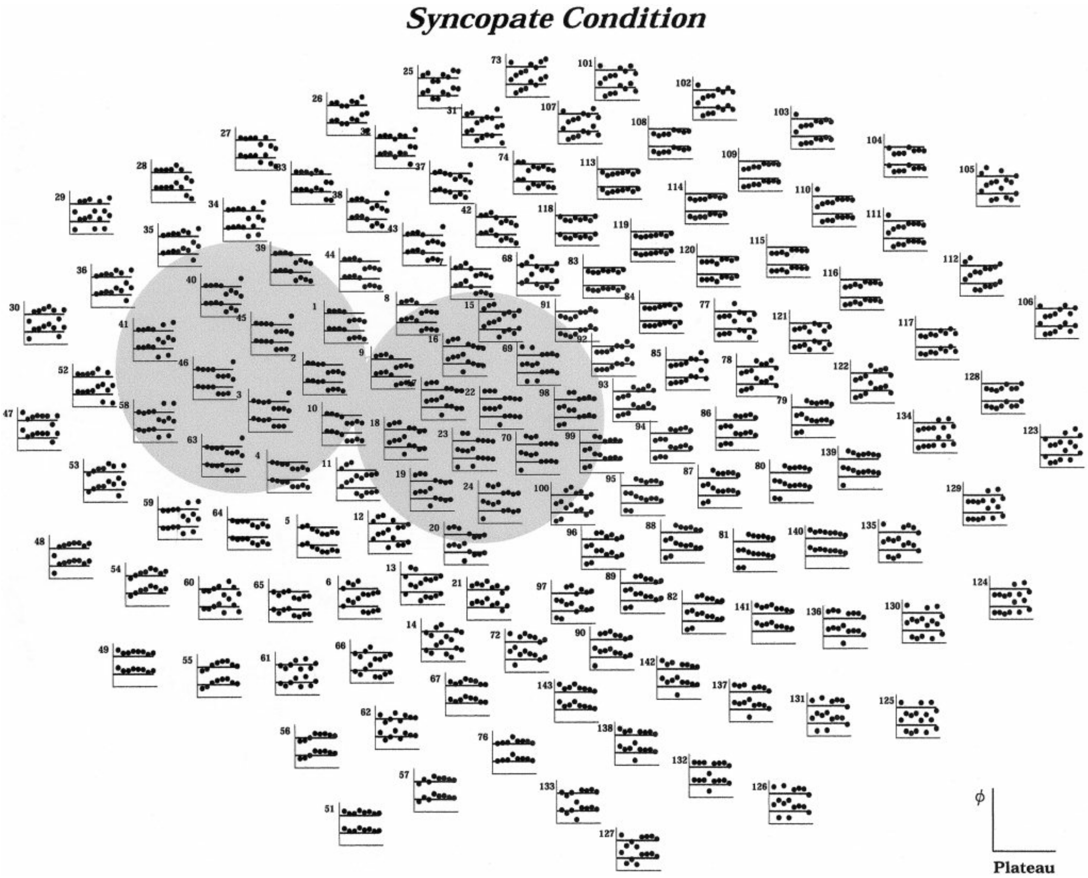
At low metronome rates, auditory response pattern dominates the topographic plots between 75-100 msec (N1m), but disappears at high rates.

The next strongest component is the motor-related pattern that occurs during the flexion phase and presenting its strongest amplitude at the instant of maximal finger velocity in the flexion direction.

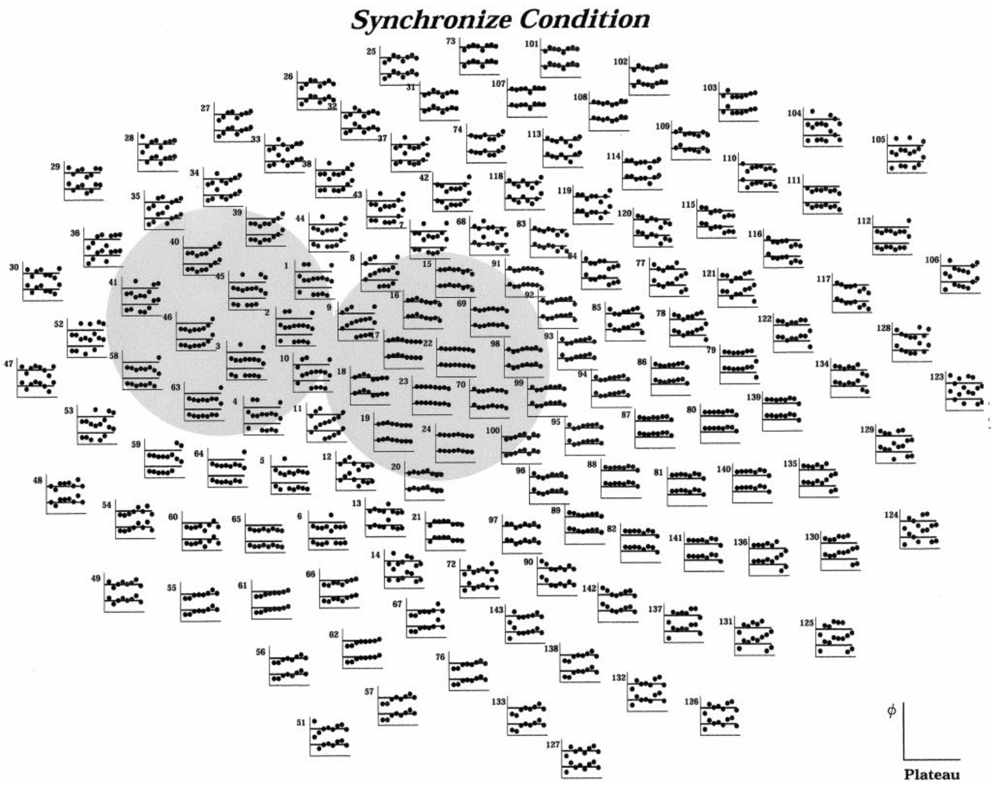


The timing of the motor-related pattern can be tracked by plotting the phase of the coordination frequency component of the event-related field**.**

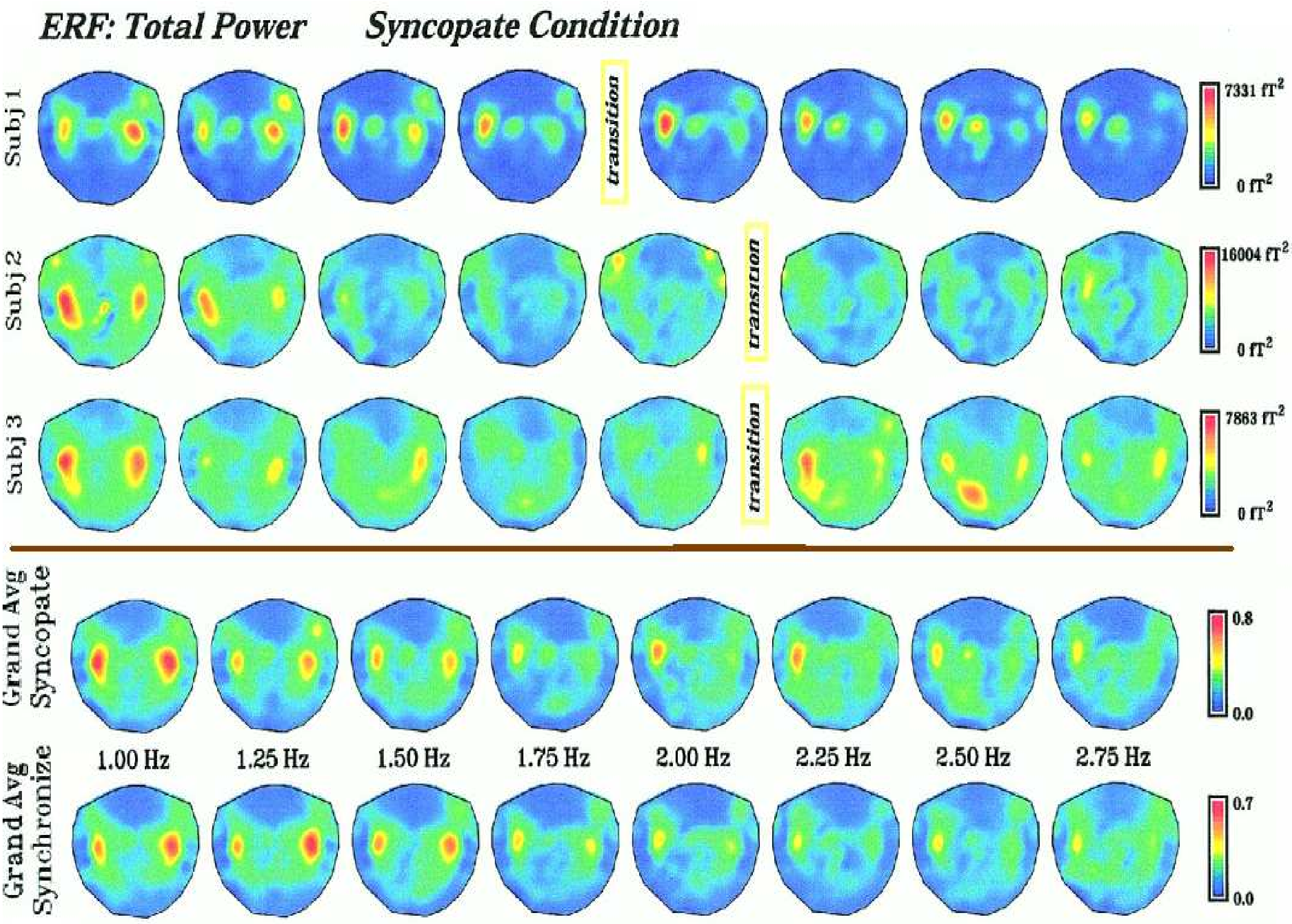
Coincident with the transition on the behavioral level, during the syncopation task, is a 180^o switch in phase measures in left central sensors. Only sensors over the left sensorimotor area show this shift.



During the synchronization task there is no such phase switch



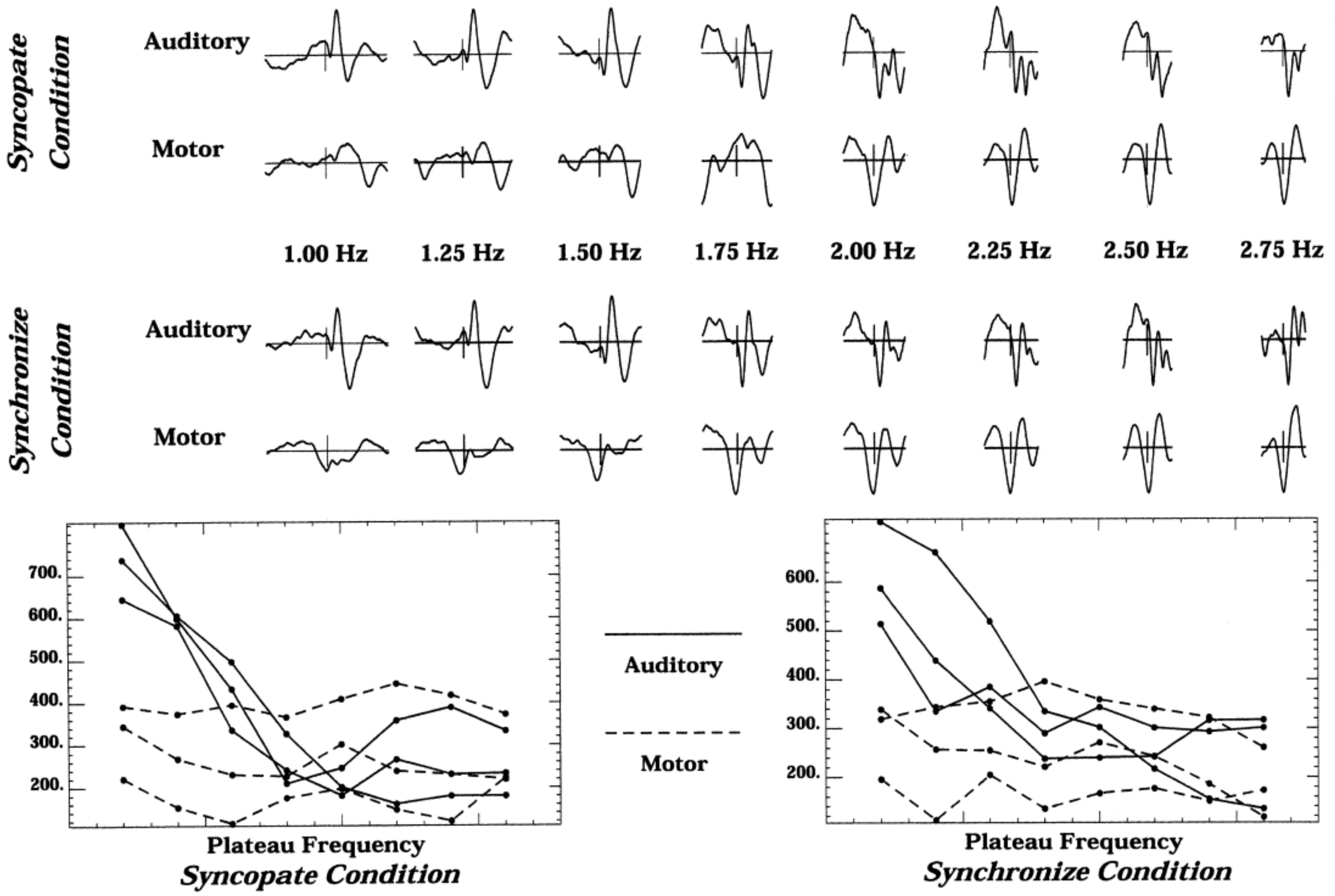
Amplitude differences in event-related fields were first examined by plotting the total power of the MEG signal



No difference in amplitude between conditions.

Interesting amplitude differences as a function of the metronome rate: Rate-dependent strengthening of the motor relative to the auditory response.

To quantify the relative contribution of auditory and motor-related processes to the event related fields, the ***dual-basis technique*** was employed.



The temporal evolution corresponding to the auditory pattern shows a qualitative transition on plateau 4 at which point the N1m-P2m complex reverses in polarity.

The motor pattern also shows a qualitative change characterized by a strong oscillation at about twice the cyclic rate at high plateaus that explains previous reports of frequency doubling in the event-related field signal.

In synchronize condition the auditory response declined much more gradually. This difference between conditions suggests that there may be differences in the way auditory information is processed when subjects are required to time movements between successive tones versus simultaneously with them

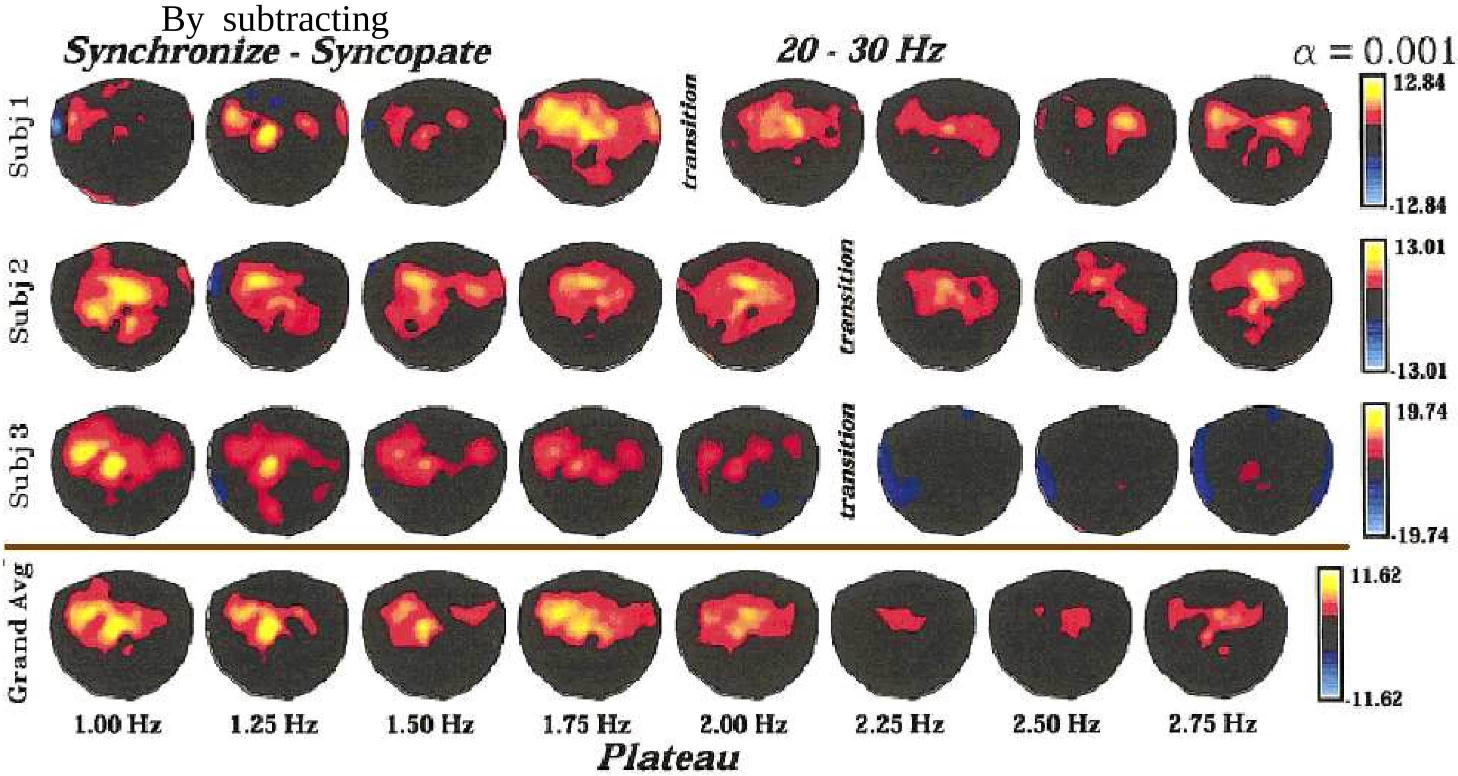
➲ Coordination conditions: task-related activity in higher frequency bands

High frequencies are not necessarily phase-locked to any task event and therefore may average out by **time-domain ensemble averaging**

Comparative Analysis of the two conditions in the **Frequency Domain** showed:
No differences in the ***Mu rhythm*** range (~10 Hz) and ***Gamma band*** (35-45 Hz):

Consistent significant differences in the *Beta* range (15-30 Hz)

By subtracting



❶ The differences are concentrated over the left hemisphere, though they do extend across the midline. **The activity in the contralateral sensorimotor cortex and perhaps also premotor and ipsilateral sensorimotor area changes in association with the mode of coordination.**

❷ More Beta power in the Synchronize condition: i.e. **suppression of beta activity during syncopation**, which is the more difficult task

❸ After transition to synchronization 2 subj. continued to show significant differences: the strength of Beta rhythm depends also on the previously performed coordination pattern, i.e. **there is a "history-effect" of syncopation**.

❹ " Neural populations responsible for Beta rhythms react to the way in which movement is organized in a given environmental context"

Conclusions

❒ "Changes in auditory-related activity reflect a transition to an increasingly steady state response that results not only in the habituation of auditory cortical neurons, but also in a reorganization of sensorimotor integration networks leading to an inability to separate the motor response from each tone event".

❒ ❒ Syncopated task is associated with a stronger ERD in ***beta*** range

❒❒❒ However, ***mu rhythm*** did not differentiated between conditions:

…… ➥ There are at least two distinct neuronal mechanisms

Discussion

➊ ERP + ERD/ERS superposition:

➋ single-trial resolution

➌ "Neuromagnetic activity in alpha and beta bands reflects learning-induced increases in coordinative stability"

[Clinical Neurophysiology, 2001]

"Statistical Analysis of Timing Errors"

[Brain and Cognition, 2001]