Presentation to be given at Human.Systems 2001: The Conference on Technologies for Human Factors and Psycho-Social Adaptation, NASA Johnson Space Center, June 20-22, 2001.

Title: MULTIMODAL NEUROELECTRIC INTERFACE DEVELOPMENT

Leonard J. Trejo, Kevin R. Wheeler, Charles C. Jorgensen

Abstract (paper presentation)

This project aims to improve performance of NASA missions by developing multimodal neuroelectric technologies for augmented human-system interaction. Neuroelectric technologies will add completely new modes of interaction that operate in parallel with keyboards, speech, or other manual controls, thereby increasing the bandwidth of human-system interaction. We recent demonstrated the feasibility of real-time electromyographic (EMG) pattern recognition for a direct neuroelectric human-computer interface. We recorded EMG signals from an elastic sleeve with dry electrodes, while a human subject performed a range of discrete gestures. A machine-learning algorithm was trained to recognize the EMG patterns associated with the gestures and map them to control signals. Successful applications now include piloting two Class 4 aircraft simulations (F-15 and 757) and entering data with a "virtual" numeric keyboard. Current research focuses on on-line adaptation of EMG sensing and processing and recognition of continuous gestures. We are also extending this on-line pattern recognition methodology to electroencephalographic (EEG) signals. This will allow us to bypass muscle activity and draw control signals directly from the human brain. Our system can reliably detect μ-rhythm (a periodic EEG signal from motor cortex in the 10 Hz range) with a lightweight headset containing saline-soaked sponge electrodes. The data show that EEG μ-rhythm can be modulated by real and imaginary motions. Current research focuses on using biofeedback to train of human subjects to modulate EEG rhythms on demand, and to examine interactions of EEG-based control with EMG-based and manual control.

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Multimodal Neuroelectric Interface Development

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PART 1

EMG Interface Development

Neuroengineering Laboratory

May, 2001

Trends in Personal Computing

Laptops and PDAs have been evolving as follows:

Larger screens - size limited by carrying convenience, can be replaced by active display glasses.

Smaller, faster motherboards - wearable cases

Spoken command input - speech recognition works for common words but not good for programming and science tasks

Full size keyboards - Design has NOT evolved. The physical size of input keys limits the evolution of cell phones, laptops, command panels, aircraft instrumentation ...

Neuroelectric NASA Applications

Wearable Cockpit - virtual instrumentation, moves with pilot, works for AUVs and manned missions. Provides for faster and cheaper reconfiguration, and safety monitoring of pilots.

Spacesuit restricted typing - allows for typed data entry while wearing spacesuit or within confined environments.

Natural robotic arm interface - joystick can be replaced with a more natural interface.

Exoskeleton EMG interface - provides capability of working in extreme environments and manuvering heavy items. Provides for training exoskeleton to do tasks autonomously.

Electrode Types & Locations

Electrode Types:

- *Wet temporary* - Ag/Ag Cl stick on temporary electrodes
- *Wet gel/metal cups* - attached with super glue
- *Dry* - metallic composition affixed by elastic

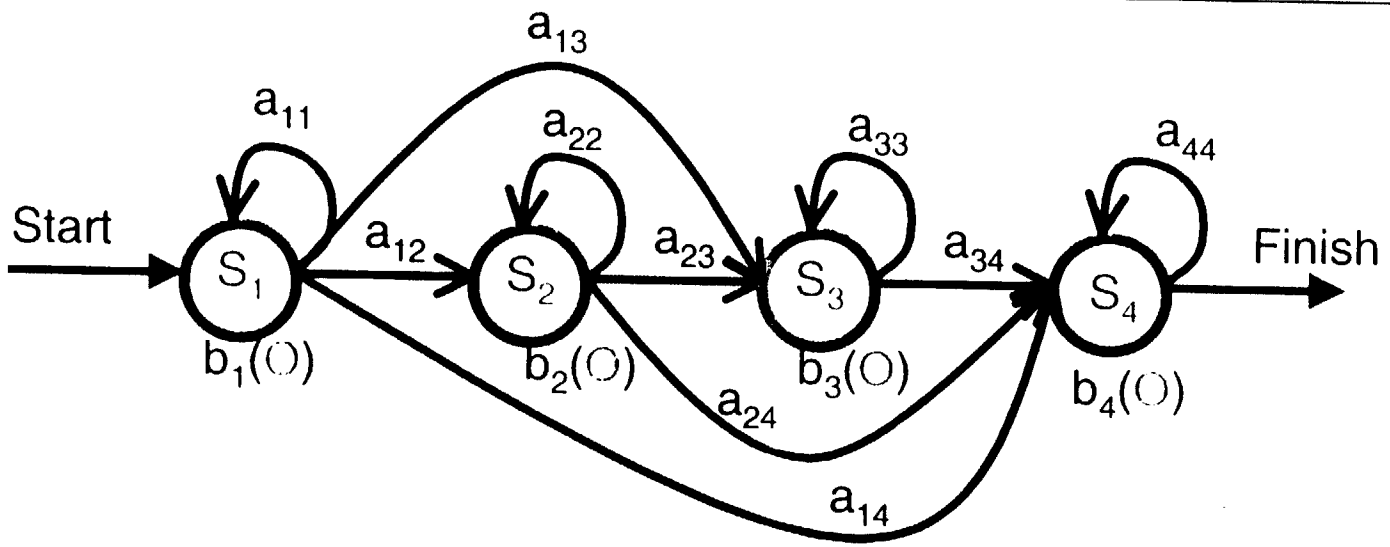
Electrode Positions:

- *Broad gestures* - larger muscles, similar across people
- *Finer gestures* - proper position requires spatial over-sampling with reduction.

Example Placement:

- *Joystick* - four electrode pairs on forearm
- *Typing* - eight electrode pairs on forearm

Hidden Markov Models



a_{ij} $P(q_{t+1}=S_j|q_t=S_i)$ transition probability from state i to state j

S_j State j,

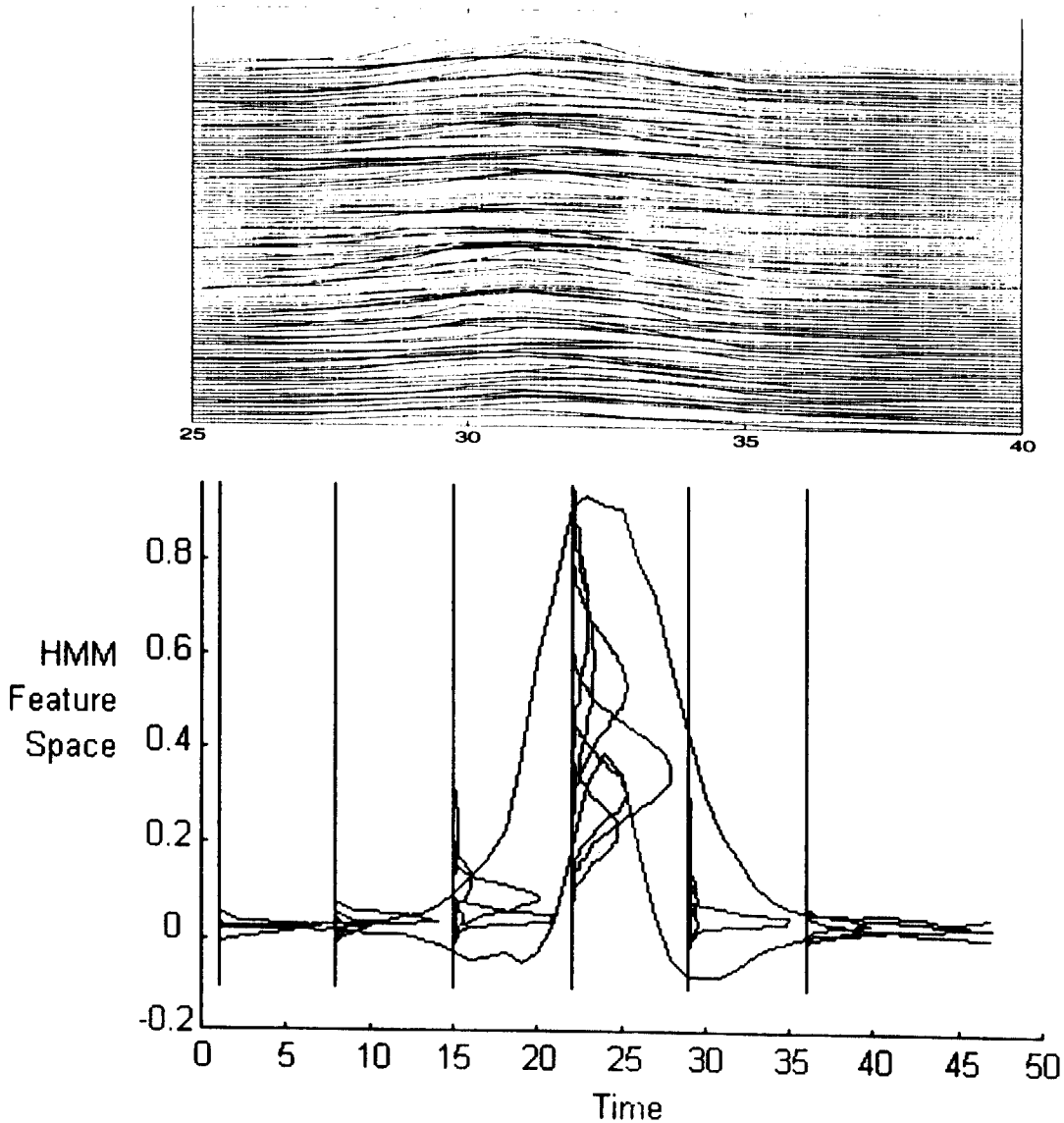
π_j probability of state j

$$b_j(O) = \sum_{m=1}^{M} c_{jm} N[O,\mu_{jm}, \Sigma_{jm}] ,$$ mixture model

Hidden Markov Model Overview

Initialization -	The initial state probability densities are formed with variance based state partitioning with per state clustering.
Features -	Overlapping moving averages of the absolute values of the signals.
Training -	Standard Baum-Welch training is employed.
Recall -	Viterbi based recall is used.
Real-time Recall -	Uses multiple identical recognitions in a row.

HMM Initialization



Inference Models

Real World Problem Domain:

- Non-stationary time-series
- Non-Gaussian distributions of feature values
- Dependence between features and channels
- Real-time recall requirement
- On-line adaptation capability
- Multi-user context switching

Quick & Dirty Tradeoffs:

- Short time windows and transforms
- Mixtures, Gram-Charlier, Multi-scale
- Eliminate via mutual information
- Exp() macros, focused computations
- Vary as little as possible
- Simple voting schemes

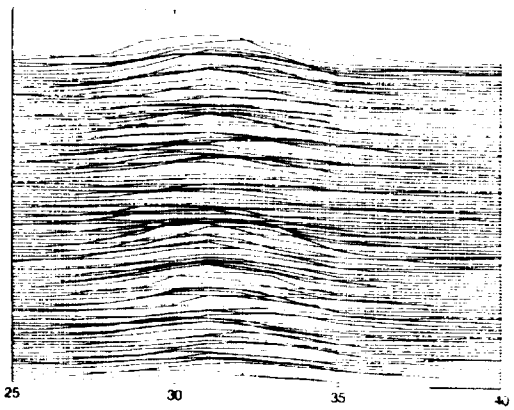
Visualization & Understanding

Error Analysis

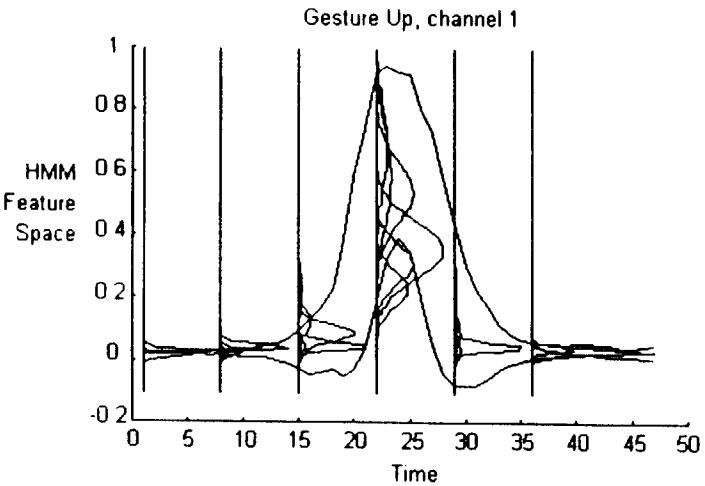
- ROC curves
- Confusion Matrix
- Error vs. parameters

Data Domain

Alternative views such as this multi-day plot.



Models



English Explanations

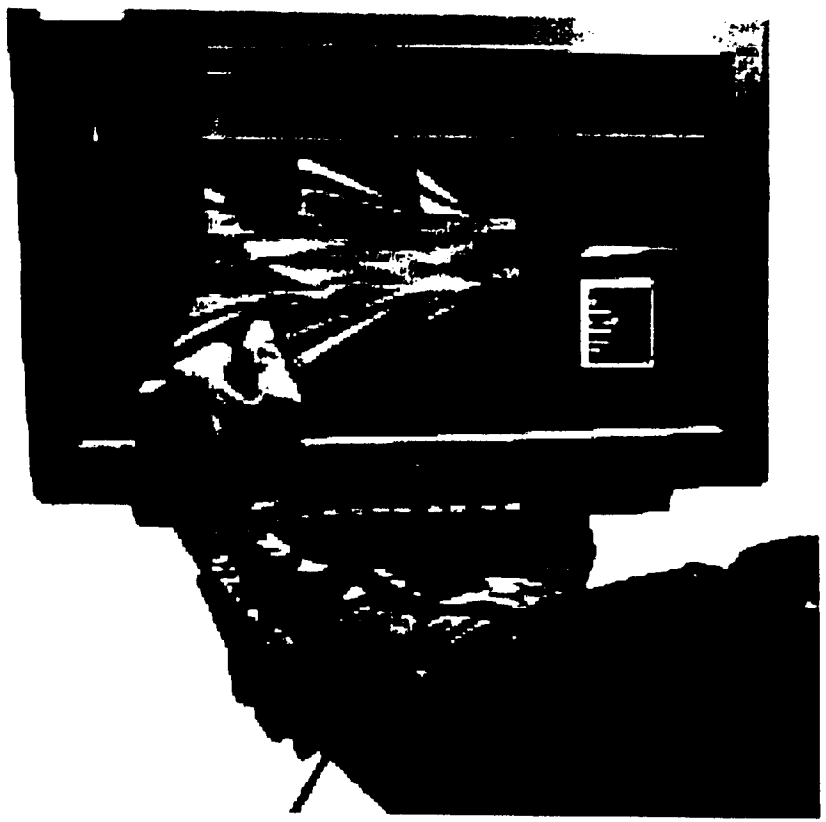
Automated transformation from model space to words:

Typing one is best separated from typing five by channel 6 time slice 4.

Aircraft Simulation

Demonstration: Eight channels of EMG are recognized as stick motions

F-15 Simulation
757 Transport Simulation



Typing Demonstration

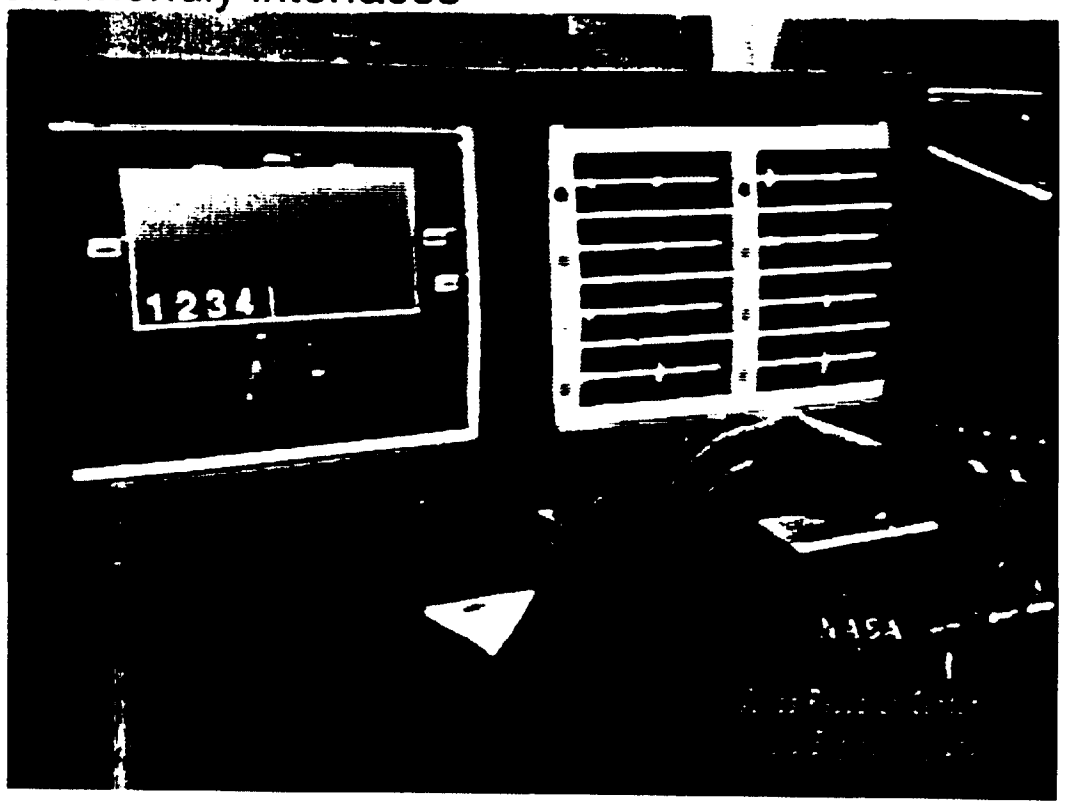
Demonstration: Eight channels of EMG are recognized as keystrokes when pretending to type on a keyboard number pad.

Purpose:

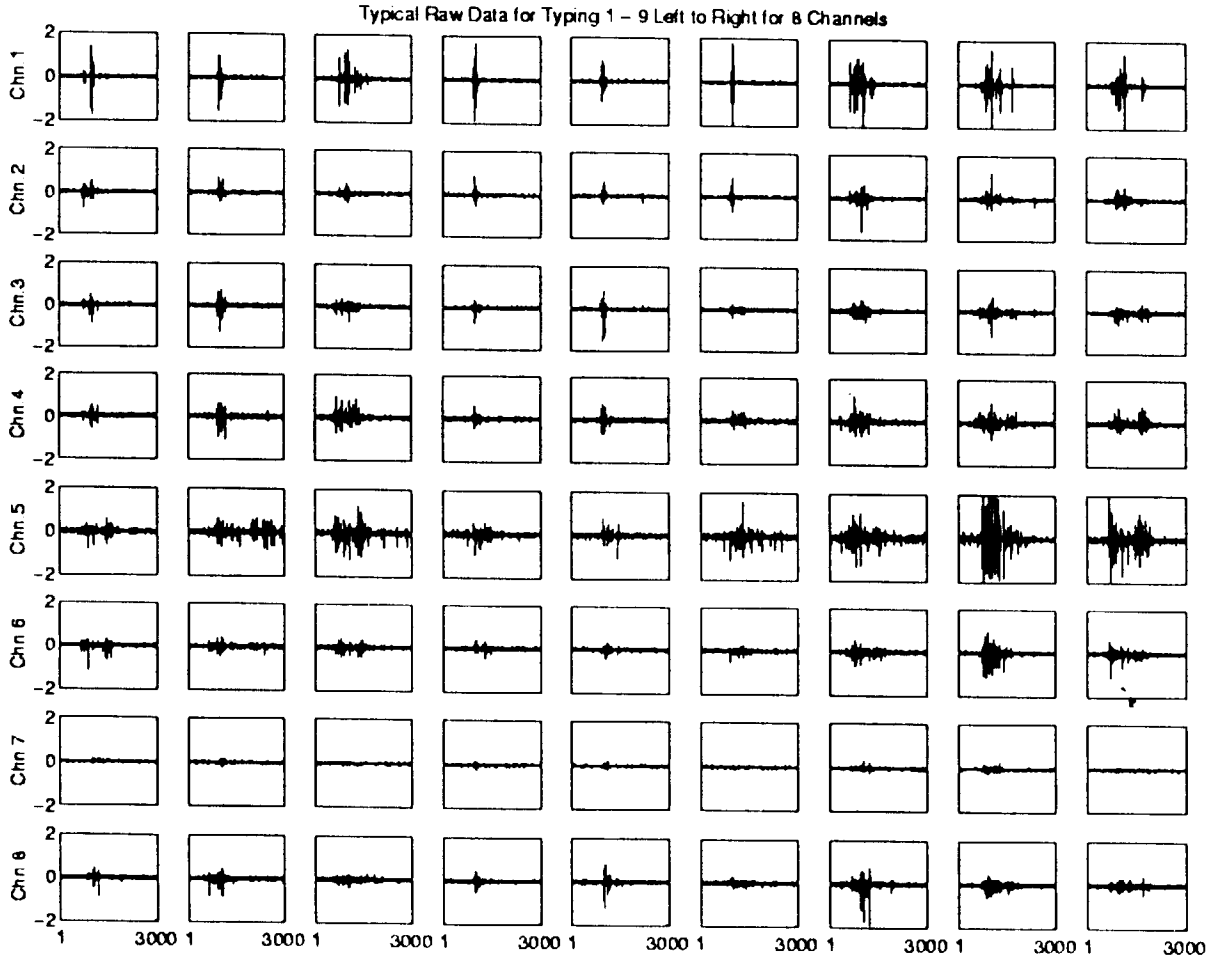
- qwerty keyboard is not the ultimate interface but it is most familiar
- alternative typing methods require additional user training
- hands are free of gloves and other apparatus
- typing capability leads to other more friendly interfaces

Issues:

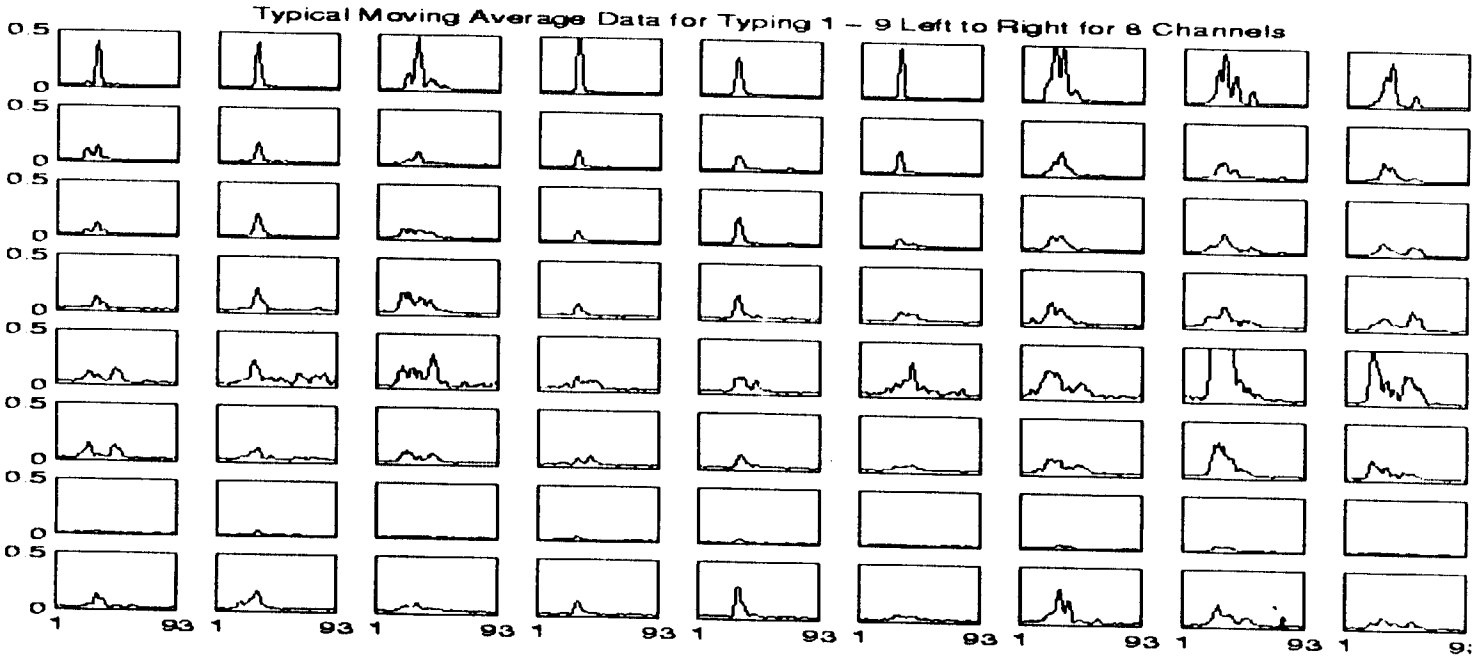
- Typing style is critical
- Finer gestures need adjustment to individual
- Small sensor development



Typing Data


Typical Raw Data for Typing 1 – 9 Left to Right for 8 Channels
Chn 1
Chn 2
Chn 3
Chn 4
Chn 5
Chn 6
Chn 7
Chn 8
2
0
-2
1
3000

Typing Data (cont'd)



Mutual Information Analysis

Mutual information measures how independent two random events are by using the information contained in their probability distributions.

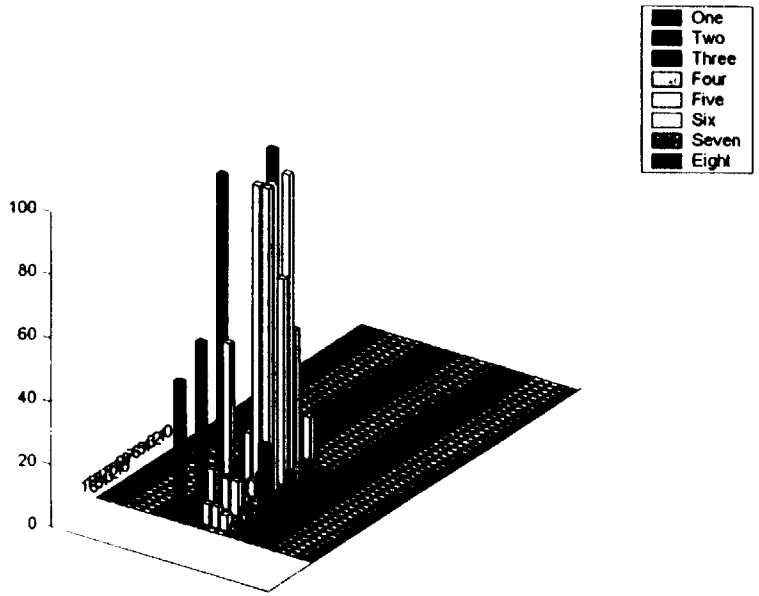
In the numeric pad typing example, the independence of the time-sliced data can be measured in a number of different ways:

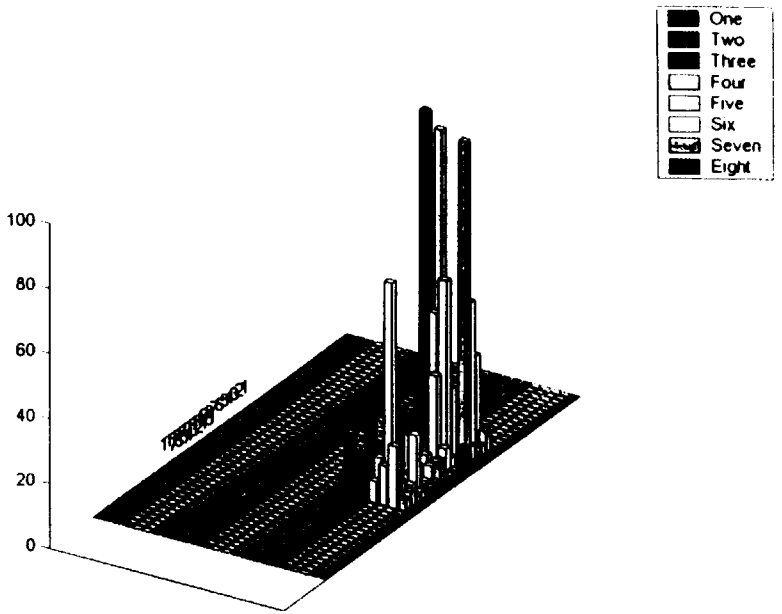
Single Time Single Channel (STSC) - one time-slice and channel for gesture X can be compared with the same time and channel for gesture Y.

Multi-Time Single Channel (MTSC) - one time-slice and one channel for gesture X can be compared with all time slices and the same channel for gesture Y.

Multi-Time Multi-Channel (MTMC) - one time-slice and one channel for gesture X can be compared with all time slices and all channels for gesture Y.

Mutual Information (STSC)





Note that different channels are important at different times for distinguishing between key presses. For "1" vs. "3" channels 5 and 6 are important, for "4" Vs. "6" channels 4 and 7 are significantly different.

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Part 2

BRAIN-COMPUTER INTERFACE DEVELOPMENT

Neuroengineering Laboratory

May, 2001

Problem

- Technology mismatch
  - Shrinking size of computers
  - Fixed size of input and control devices
- Limited bandwidth of current interfaces
- Unnatural motions
  - Repetitive stress injuries
- Risk of neuromuscular dysfunction
- Controls for restricted environments
  - Space suits
  - Mobile applications

Neuroelectric Interfaces

Why neuroelectric interfaces?

- Electrical connection to nervous system
- Bypass mechanical interfaces

Technologies

- Electromyogram (EMG)
- Electrooculogram (EOG)
- Electroencephalogram (EEG)
- Implanted electrodes (ECoG, multi-unit, FES)

Background

- Adrian (1934): eyes-open/closed alpha
- Kamiya (1958): alpha-wave biofeedback
- Basmajian(1960's): single motor unit control using EMG audio feedback
- Several labs (1980s-'90s): character recognition, cursor control (e.g. Wolpaw, et al.)
- ARC/NEL (2000): EMG gesture recognition
- Nicolelis (2000): monkey brain -- robot arm

Goals

What's New About this Research

— Previous research focus on rehabilitative medicine

— Current research focus on advanced HCI

Benefits to NASA

— New interfaces for mobile or restricted environments

— Augmented interaction in normal environments by increasing bandwidth and quickening the interface

— Enhance situational awareness by providing immediate and intimate connections

— Increased mission safety by reduced risk of injury and neuromuscular dysfunction

What We Will Do in This Project

Scientific Goals

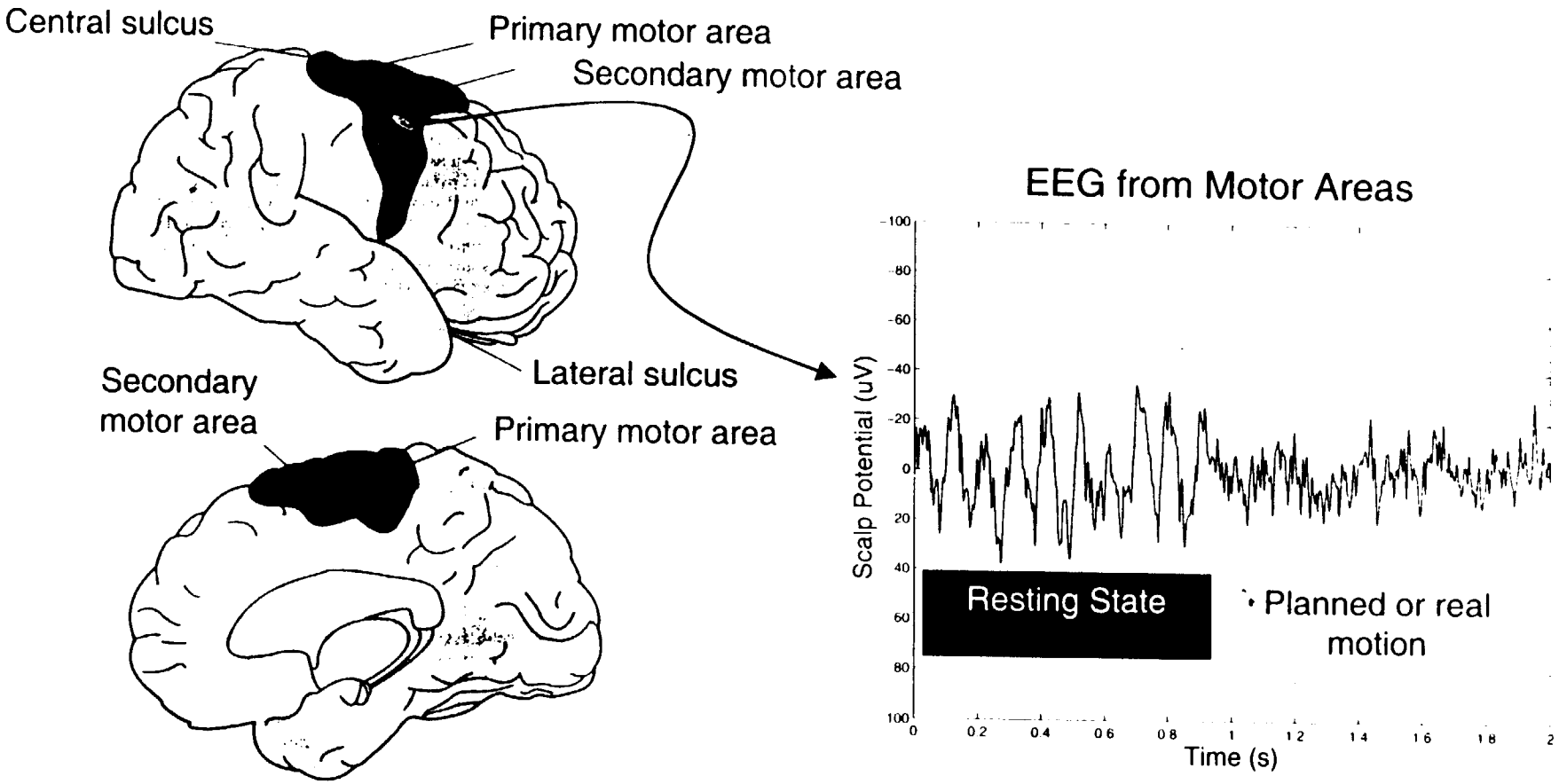
- Test feasibility of BCI for 1-D and 2-D control
- Test interactions of BCI with motion and speech
- Identify and localize EEG sources for use in multi-modal BCI interface
- Develop sensitive and accurate signal processing algorithms

Technical Goals

- Develop a real-time closed-loop 'BCI system
  - EEG recording
  - Signal processing
  - Control logic
  - Display feedback
- Demonstrate 2D BCI for data visualization control

Biophysical Basis of EEG-based Control

(Desynchronization of μ–rhythm)



(Adapted from Beatty, 1995)

Pilot Study: Detection of μ- and β-rhythms

Tasks

—Card sorting, Roulette

—Reaching, Imaginary Reaching

Recording

—EEG electrodes C3 & C4 referred to mastoid

—EMG electrode on right triceps muscle

Analysis

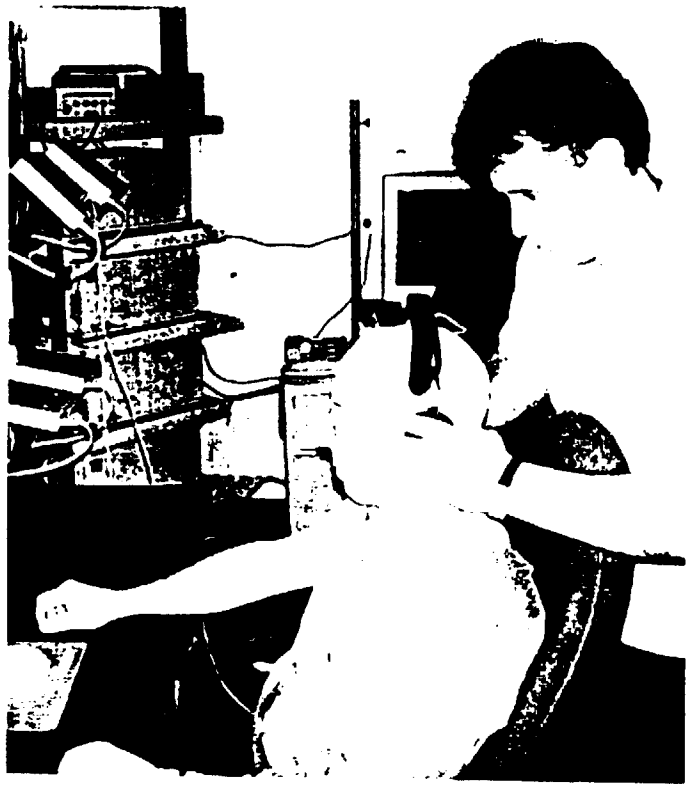
—Epoch EEG (EMG) in segments surrounding motion

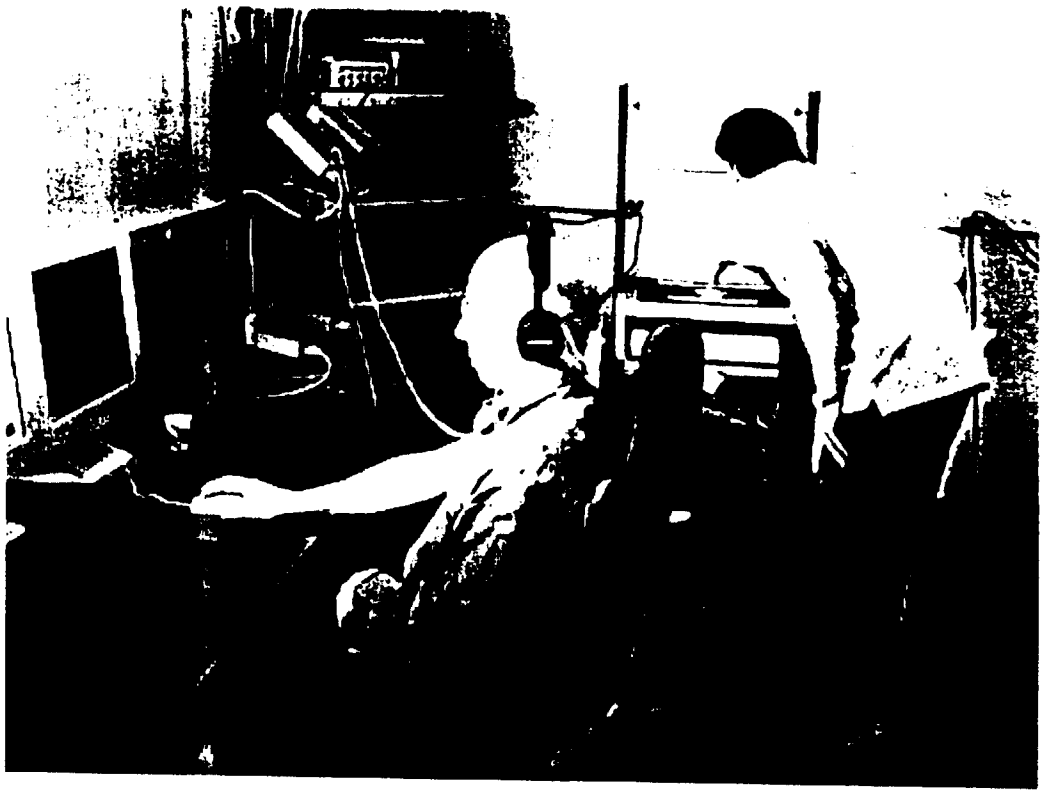
—Power spectrum of EEG (EMG) to detect bands

—Event-related band power analysis to measure desyncrhonization (ERD)

Sensorphone

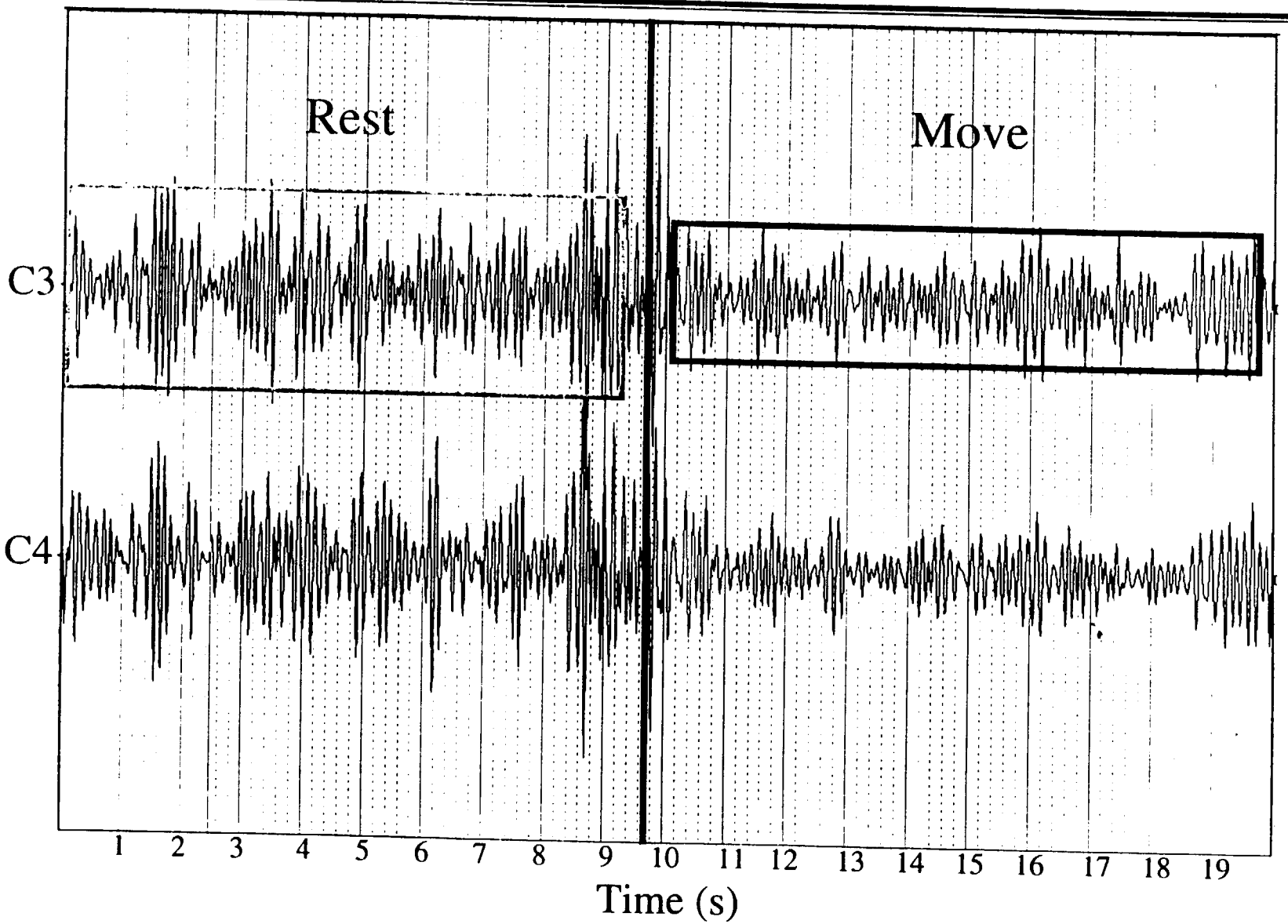
Recording





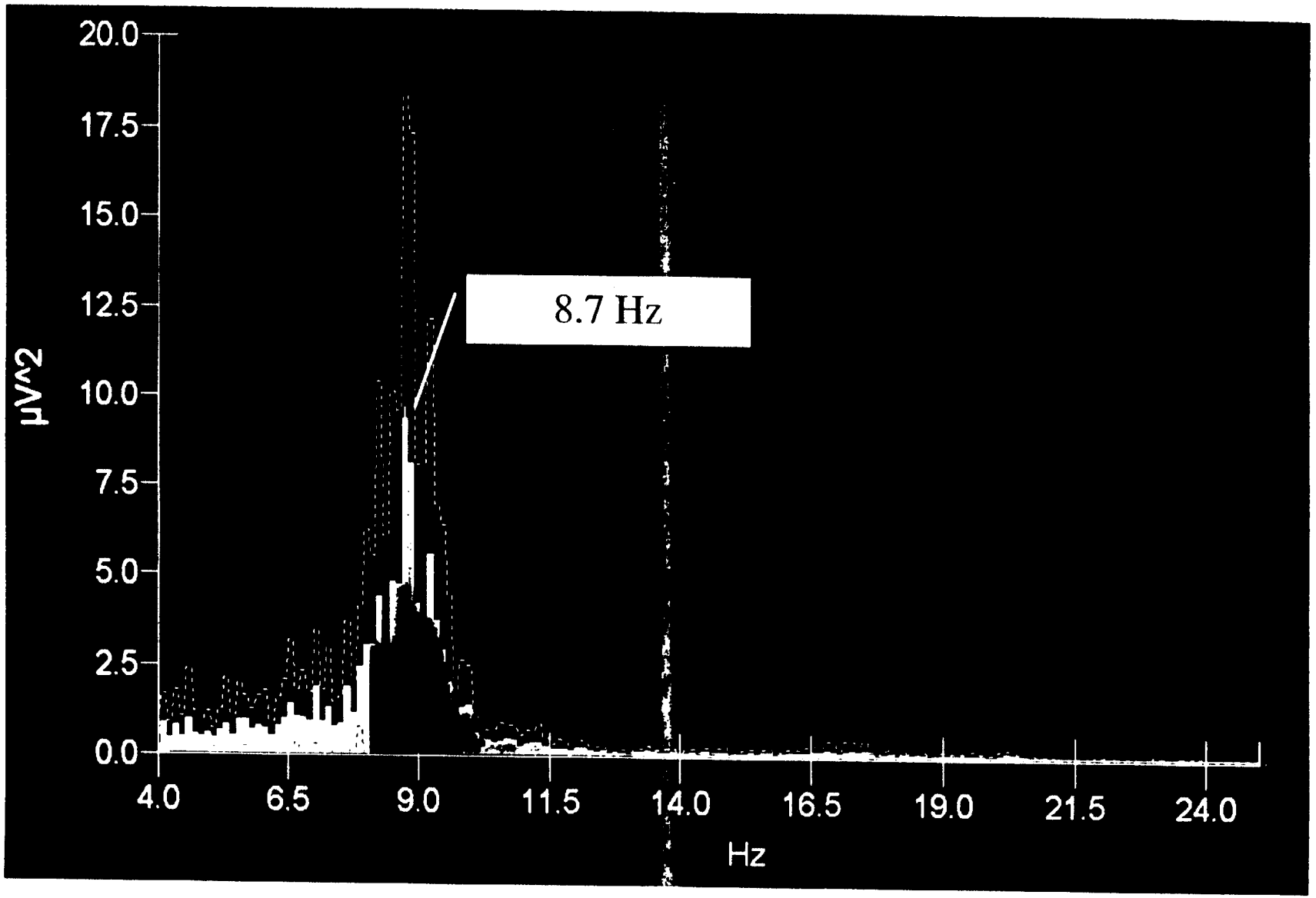
Card Sorting Task

EEG at C3 & C4. Bandpass 6-12 Hz. One epoch pre- and post- motion.



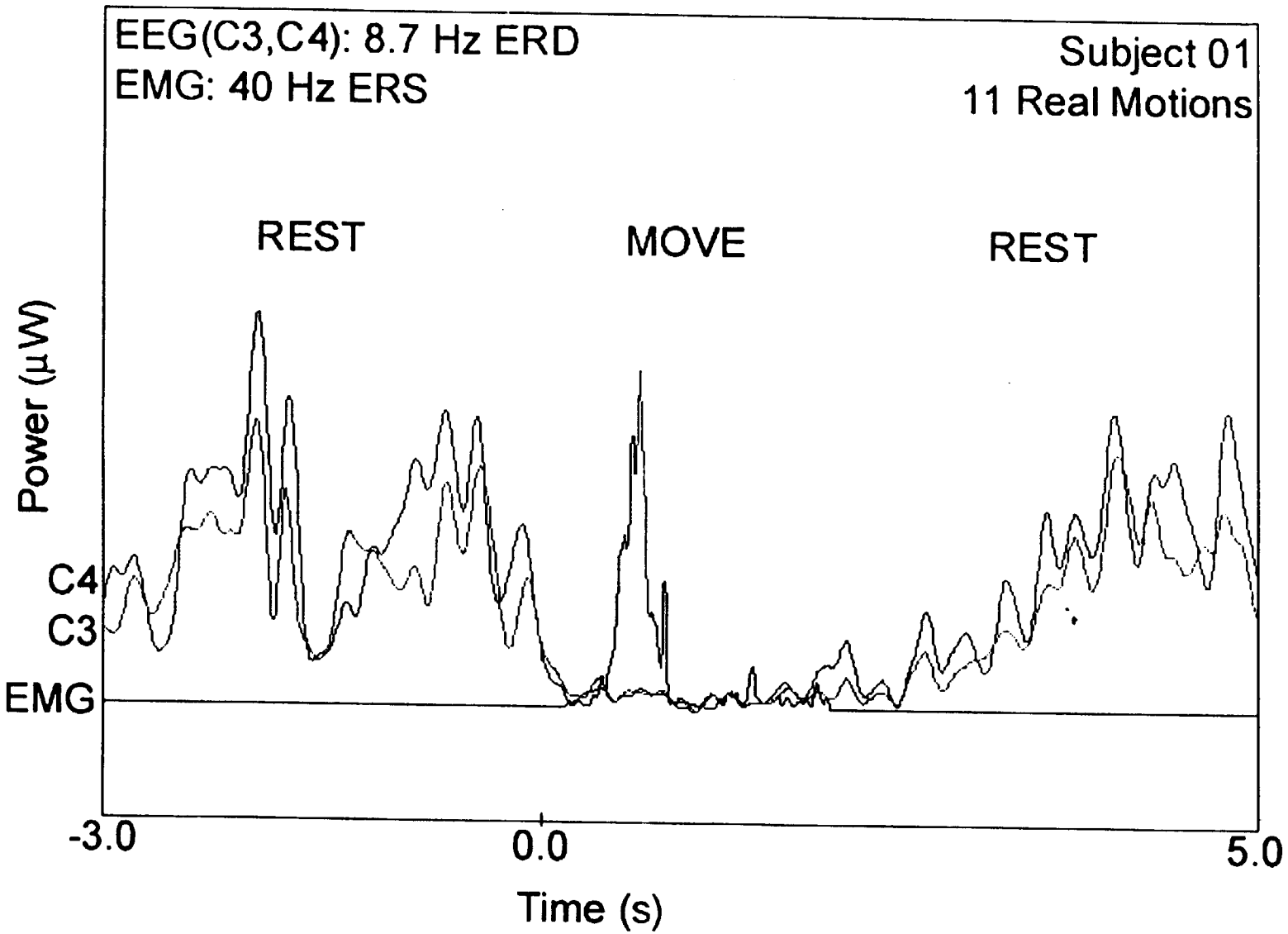
Reaching Task - Eleven Motion Epochs

Average spectrum at C3 from -5 to +3 sec relative to onset of motion

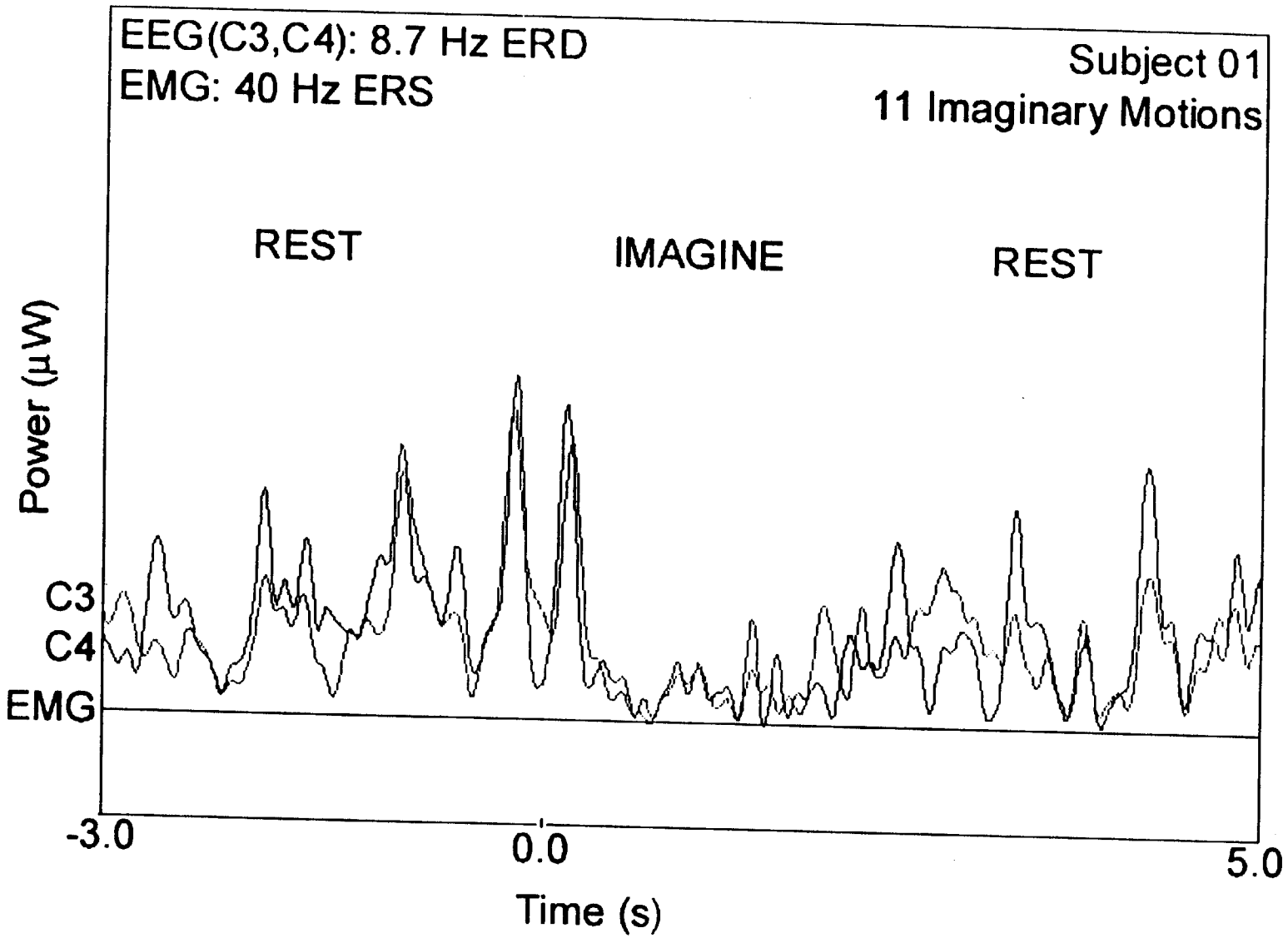


Reaching Task - Eleven Motion Epochs

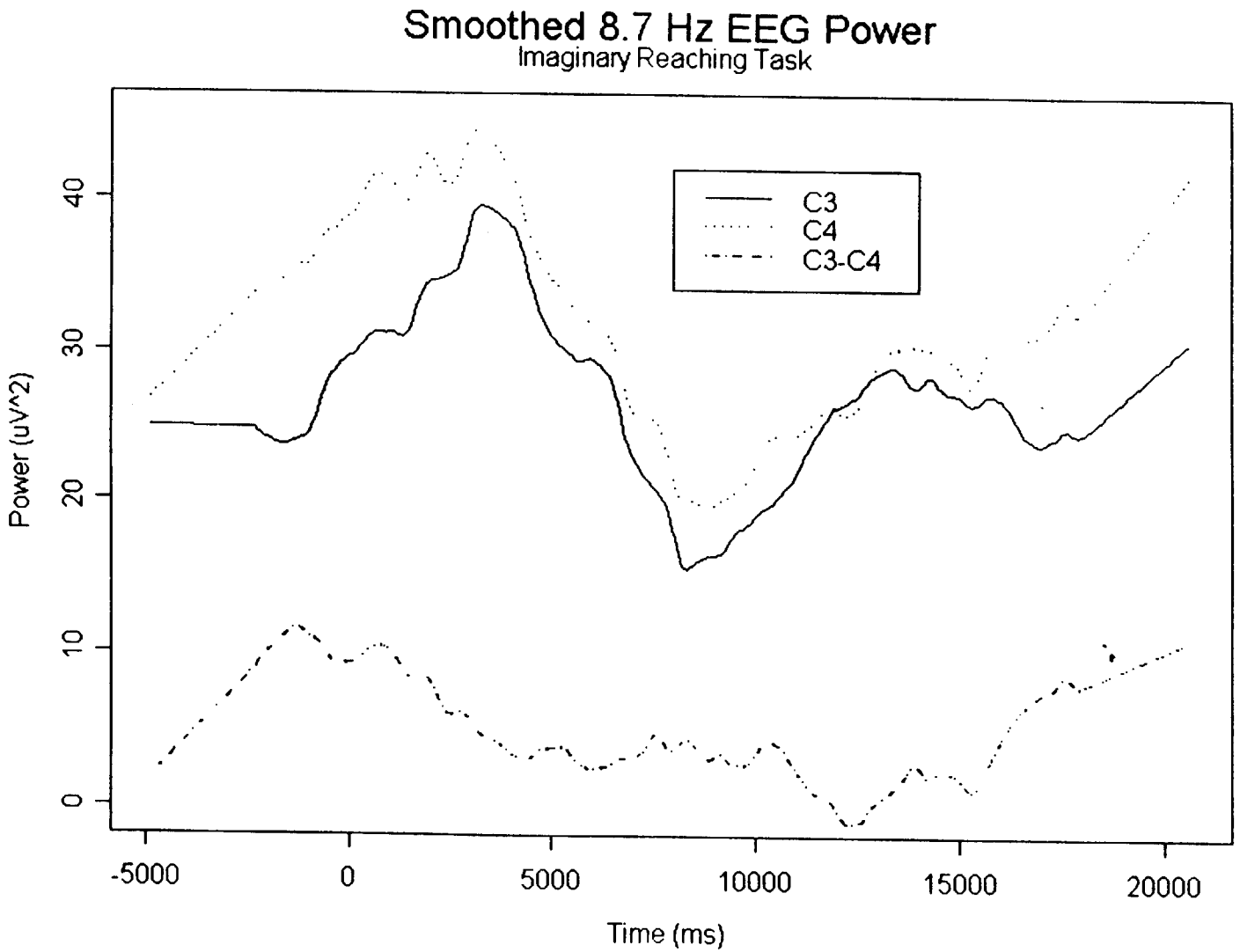
8.7 Hz ERD at C3 & C4 from -3 to +5 sec relative to onset of motion



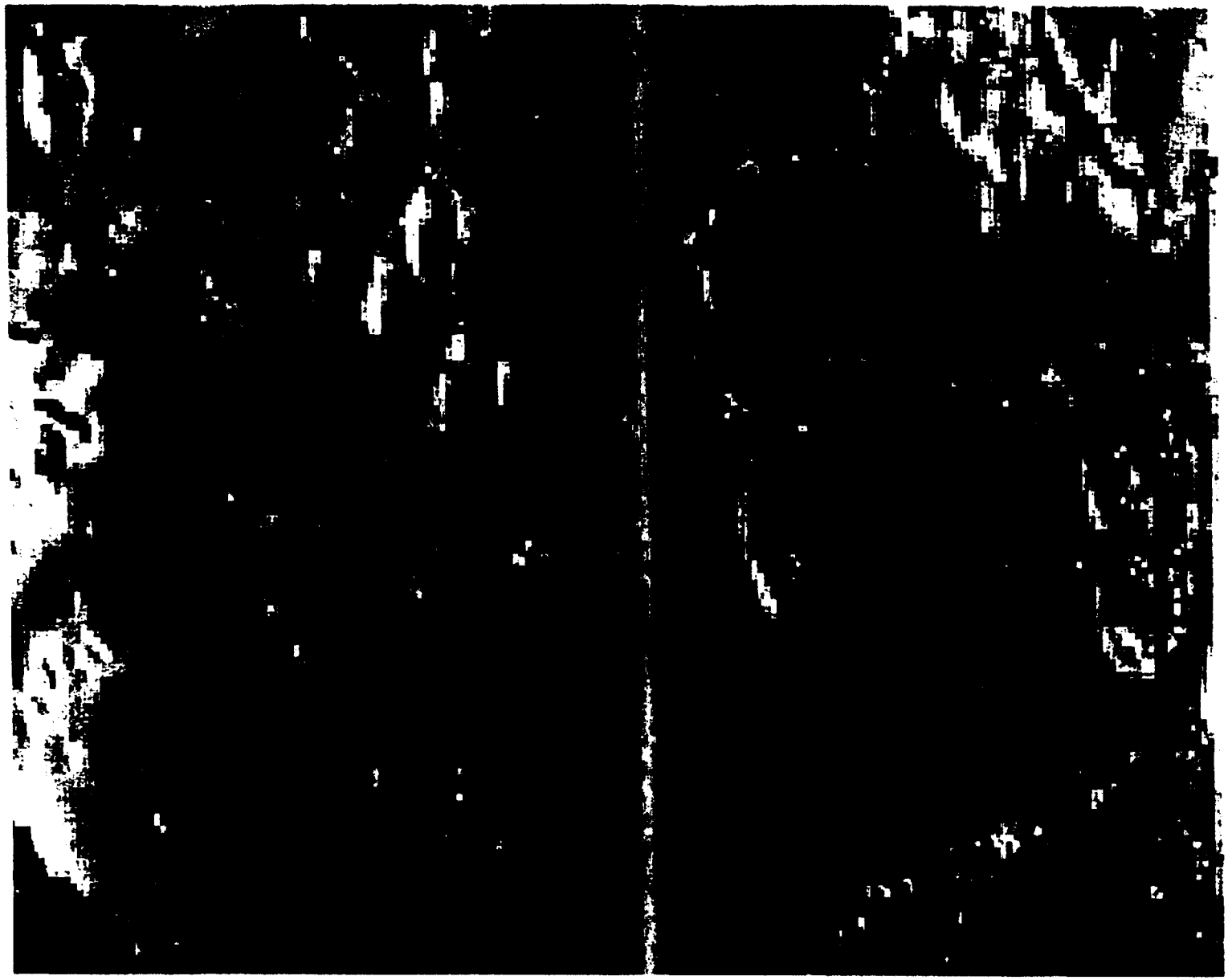
Imaginary Reaching Task - Eleven Motion Epochs
8.7 Hz ERD at C3 & C4 from -3 to +5 sec relative to onset of motion



Simulated Control Signals



Simulated BCI for Moving Map Control



Summary

ERD in Real Motion

—μ-rhythm detected in all tasks with 6 to 11 epochs

—Visible in raw data at single-trial

—Timing coincides with motion and EMG activation

—β-rhythm (20 Hz) detected in all tasks

—Timing preceded or coincided with real motion

—Lower power than μ-rhythm

ERD in Imaginary Motion

—ERD effect similar to that of real motion

—Timing coincides with command to initiate motion

—Relatively smaller change in power

—Dynamics appear suitable for 2D display control