Encoding of Tactile Stimulus Location by Somatosensory Thalamocortical Ensembles

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Scope

investigation of how **ensembles**
of simultaneously recorded single neurons
in ***layer V*** of *primary somatosensory (SI) cortex*
and in the *ventral posterior medial (VPM) nucleus* of the thalamus

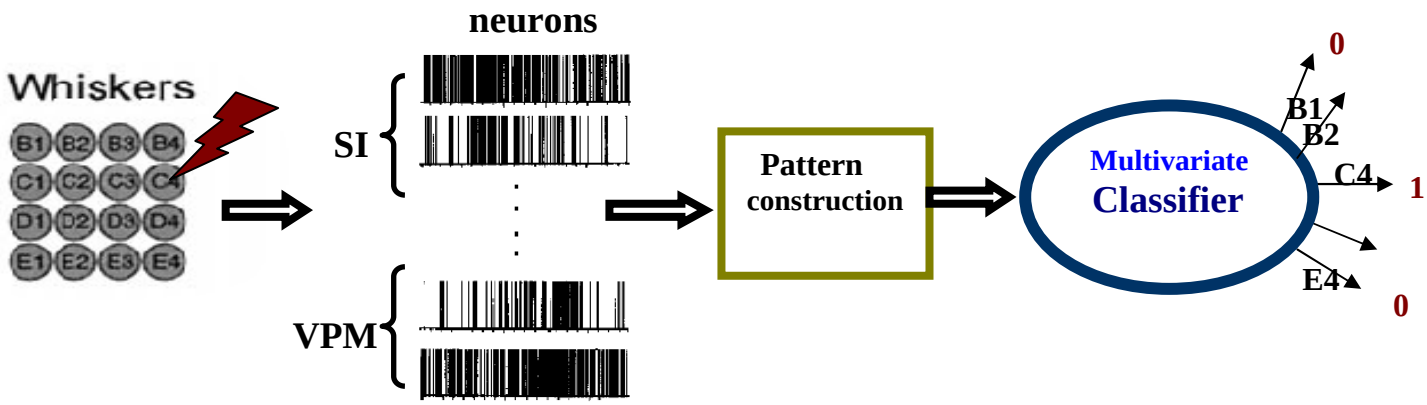
of the anesthetized rat may encode
the location of a single whisker stimulus on a ***single trial basis***

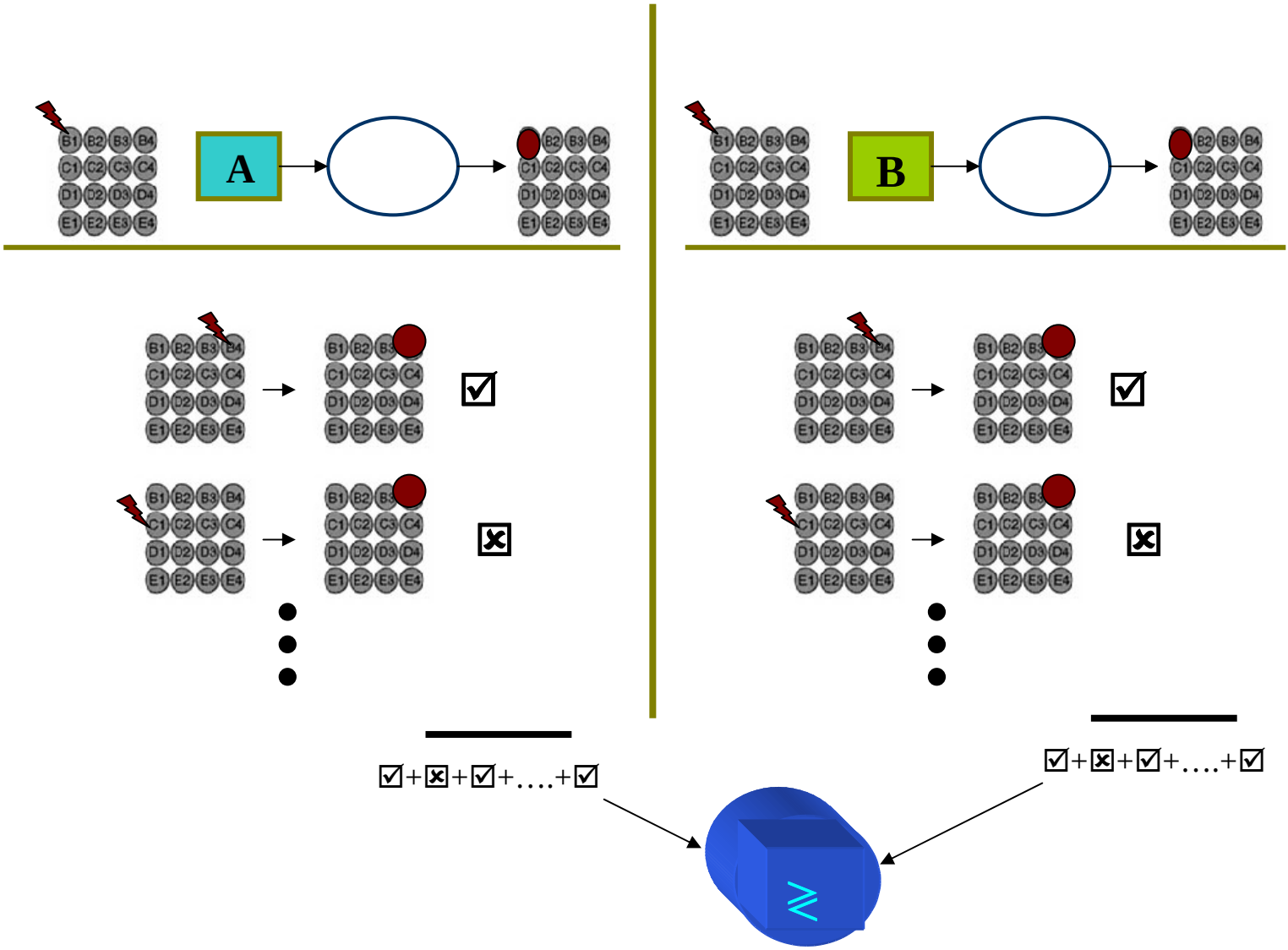
METHODOLOGICAL APPROACH

The classification of ***Single Trial*** responses as a mean to predict the tactile stimulus location.

Possible coding schemes are tested through their impact on the classification.

Hypothesis ranking based on the classification performance.





MATERIALS & METHODS

➲ DATA COLLECTION

surgical procedure

9 adult female Long-Evans rats underwent craniotomy:
16 microwires were implanted in SI barrel cortex and / or
16 microwires in the VPM nucleus of the thalamus (SI:3,VPM:3,SI&VPM:3)

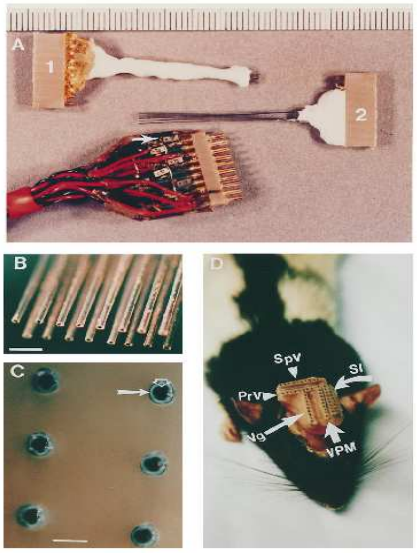
placement was targeting for neurons representing
the large, caudal whiskers (B1–4, C1–4, D1–4, and E1–4)

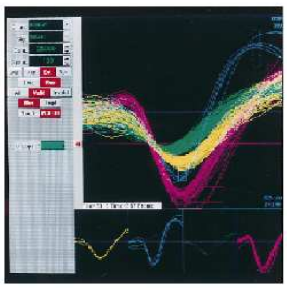
spike sorting

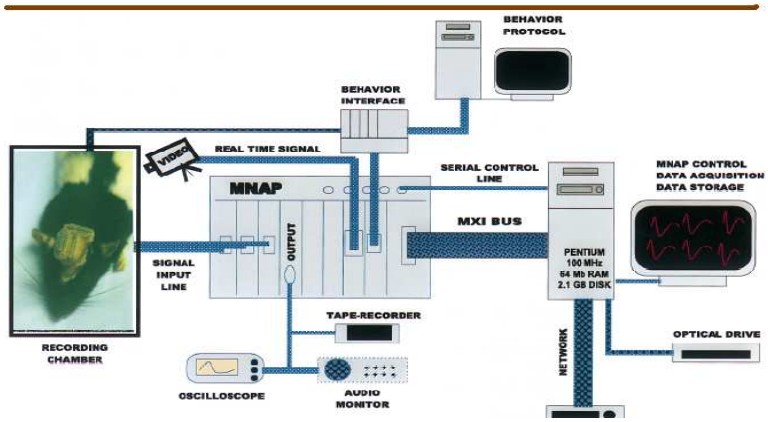
~80% of microwires yield stable single units
~2.3 single units per microwire can be well discriminated

whisker stimulation

A vibromechanical probe was delivering mechanical stimulation
to single whiskers contralateral to the microwire array implant..
The stimulus was a step-pulse (100 msec) at 1 Hz.



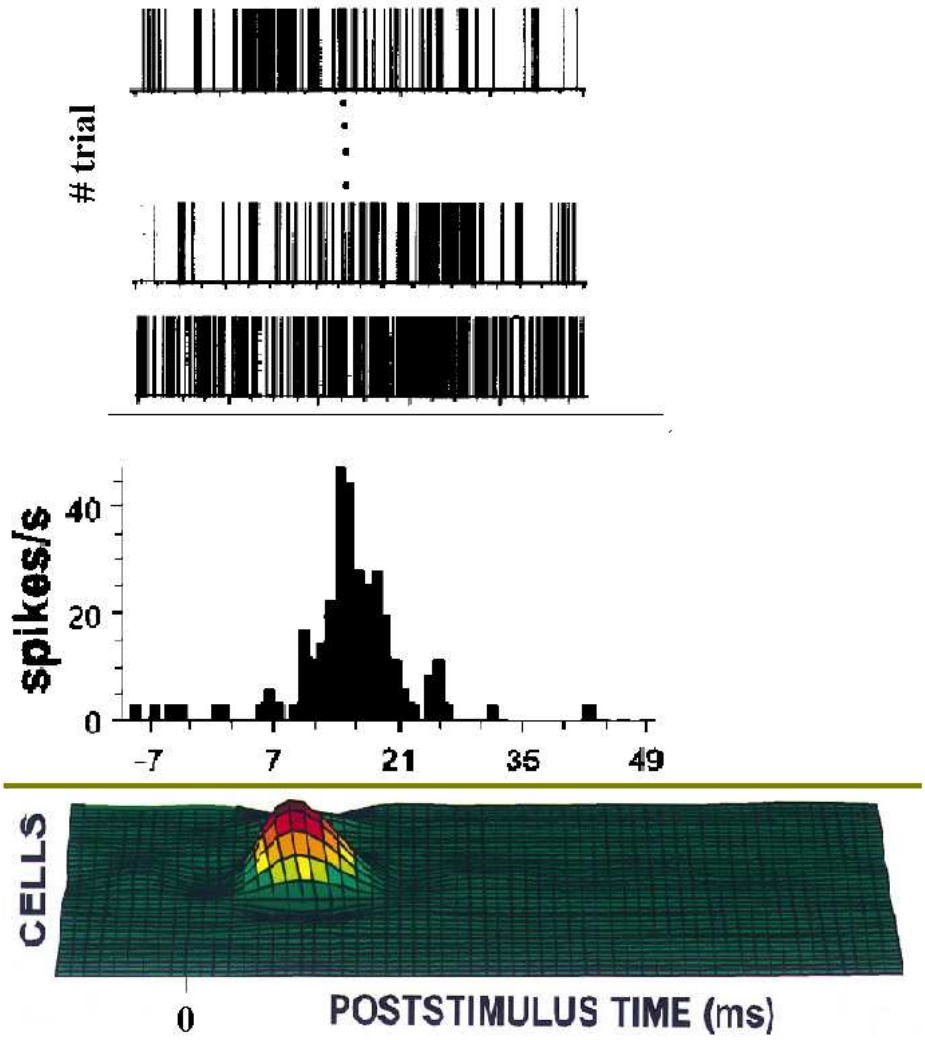




DATA ANALYSIS

Minimal Spike Latency & Average evoked firing rate
of each neuron was computed based on postimulus time (PSTHs)
and cumulative frequency (CFHs) histograms

Population histogram
Stack of single neuron PSTHs, describing sensory response of neural population to a single whisker deflection.



Single trial analysis is necessary because
(i) a large number of neurons are active after the deflection of a single whisker

(ii) there is high variability in the spike-train of each neuron from trial-to-trial

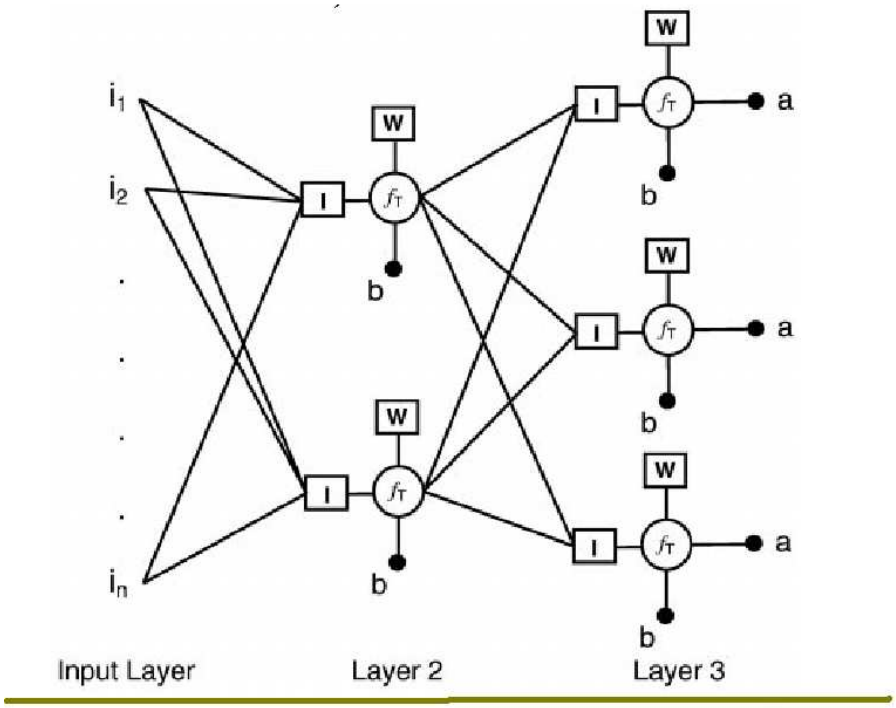
(iii) ***Pattern recognition*** approaches using multivariate statistical methods, can efficiently support such analysis identifying in a statistical predictable manner the location of the stimulus.

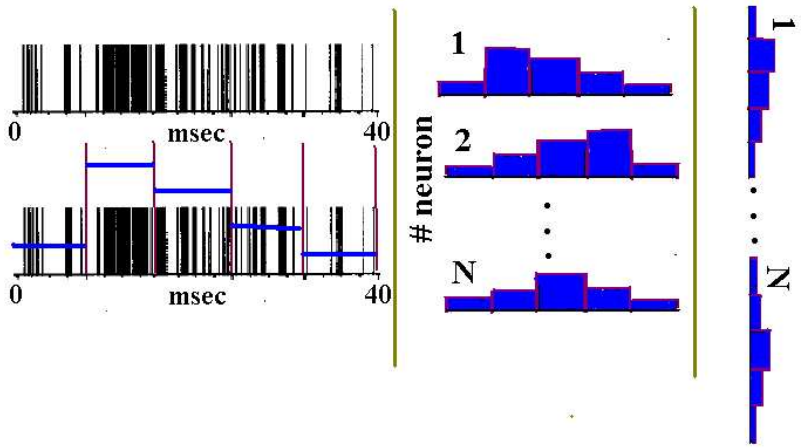
Learning Vector Quantization classifier

-thalamocortical responses to tactile stimuli, on a single trial basis, were fed to an ANN classifier.

-input patterns were based on the **firing rate** and the **temporal patterning of neuronal firing** within simultaneously recorded neurons.

- **training** & **testing phase** (25% & 75% of trials / 4-way cross-validation)





- The spike train of each neuron from 0-40 msec was used / bins of 4 msec

Exploring putative coding mechanisms

Hypothesis testing based on the Classification performance of the ANN as an index of efficiency for a possible encoding scheme:

"Raw" VS "manipulated" neural ensemble data

(i) Local vs Distributed coding

comparison of classification performance (in discriminating one whisker out of the rest) before and after the removal of the ***best predictor neuron***.

(ii) Rate vs Temporal coding (temporal structure of firing rate)

the effect of temporal modulation of ensemble firing rates was estimated by systematically varying the bin size: increase in size degrades temporal resolution

(iii) Correlated activity across neuronal spike trains ?

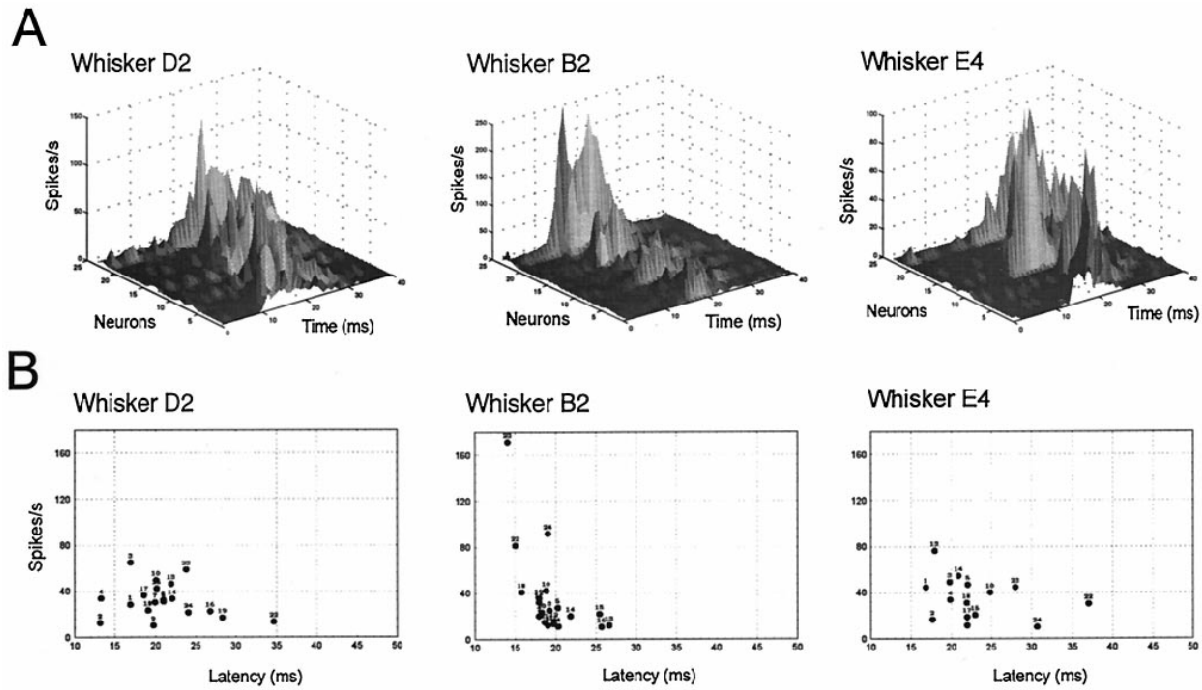
exploring the role of covariance structure on ensemble performance using ***Linear Discriminant Analysis (LDA)*** as classification scheme and comparing its performance when applied to *"normal"* / *"time -shifted"* and *"trial- shuffled"* spike trains.

(iv) Dependency in the representation of information across SI and VPM

RESULTS

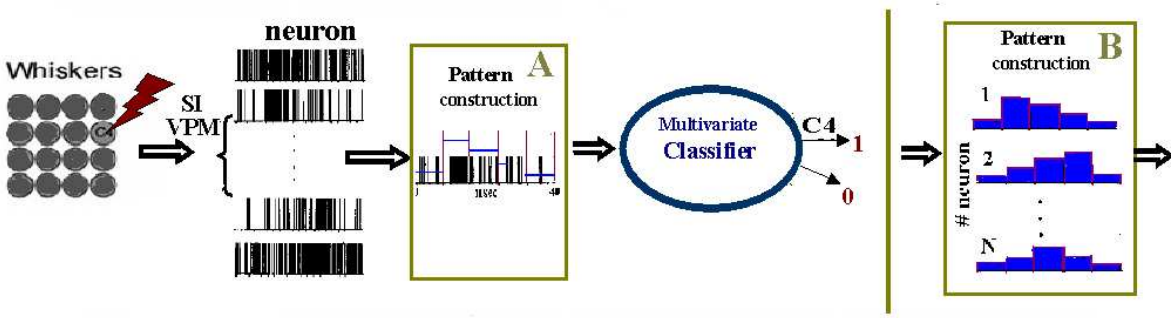
I) Stimulation of a single whisker elicits complex response

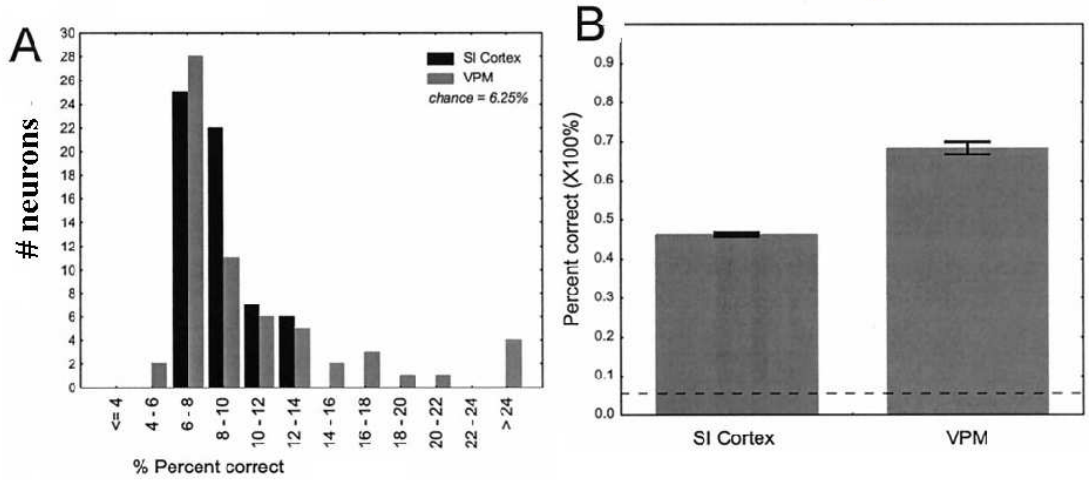
average RF: 8.5 whiskers in SI / 13.7 whiskers in VPM



(A) population histograms of SI (B) Mapping neurons in 2D "activity field"

II) Single neuron VS neural ensemble performance

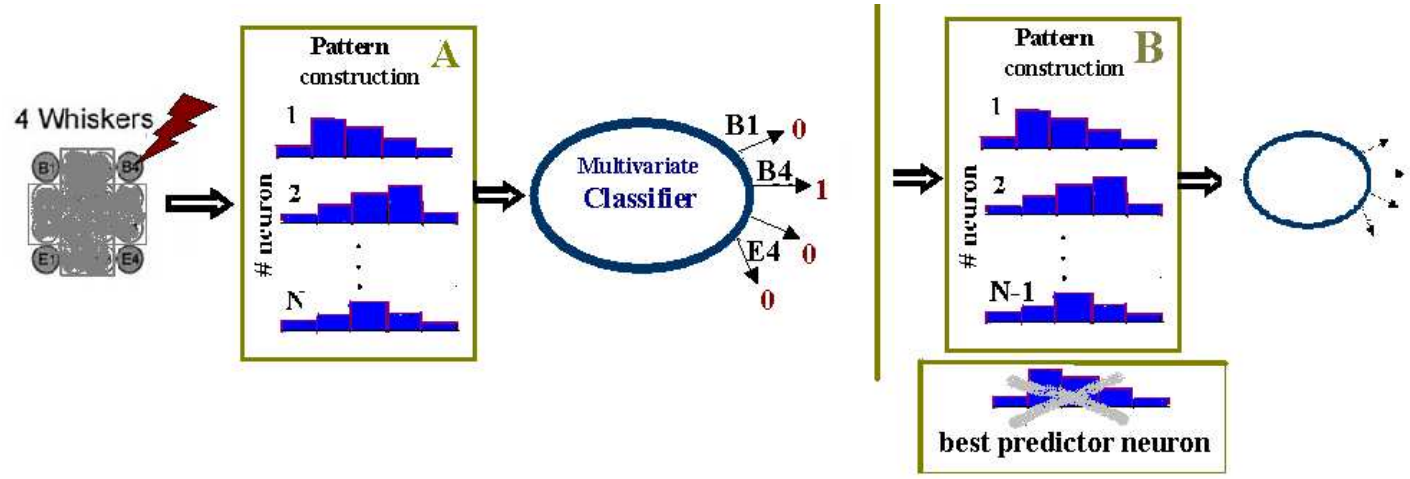


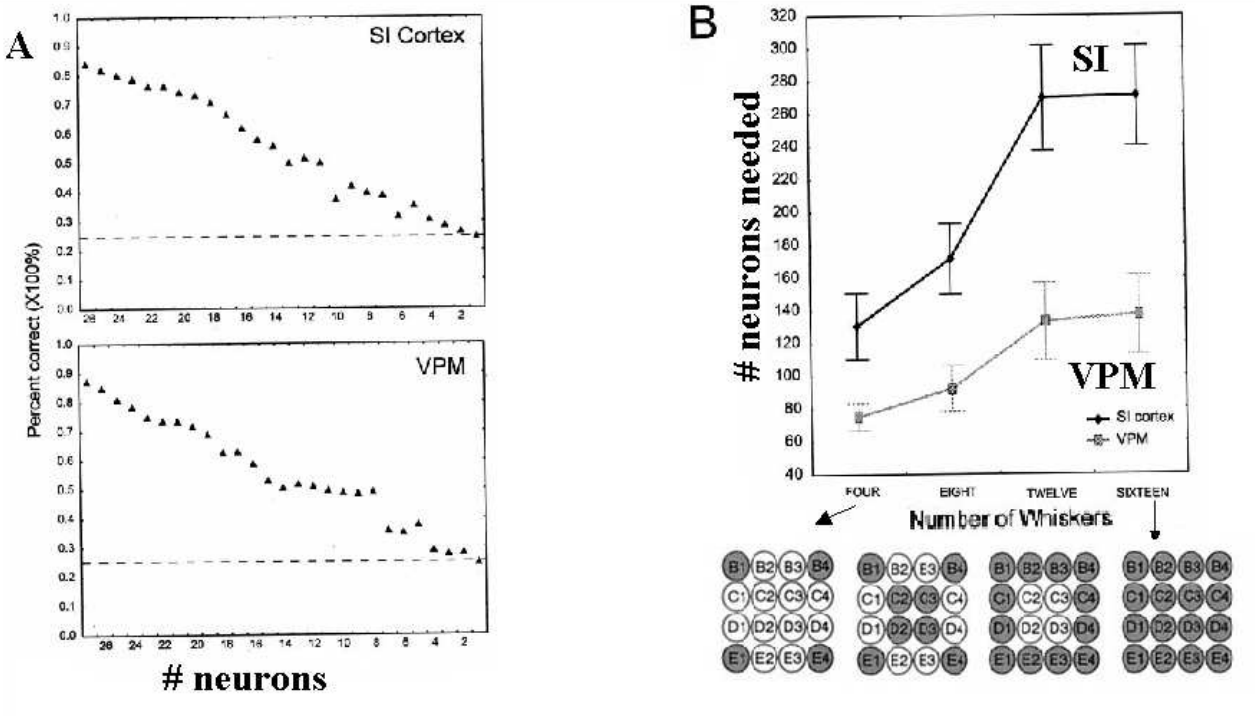


***Small neural ensembles perform several times better than chance and**

***** several times better than the best single neurons**

III) Graceful degradation of ensemble performance



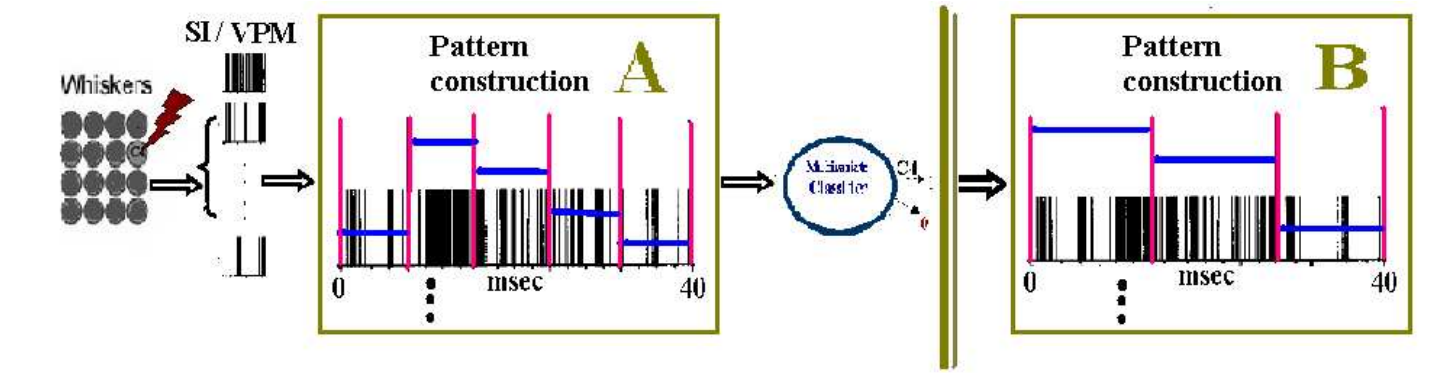


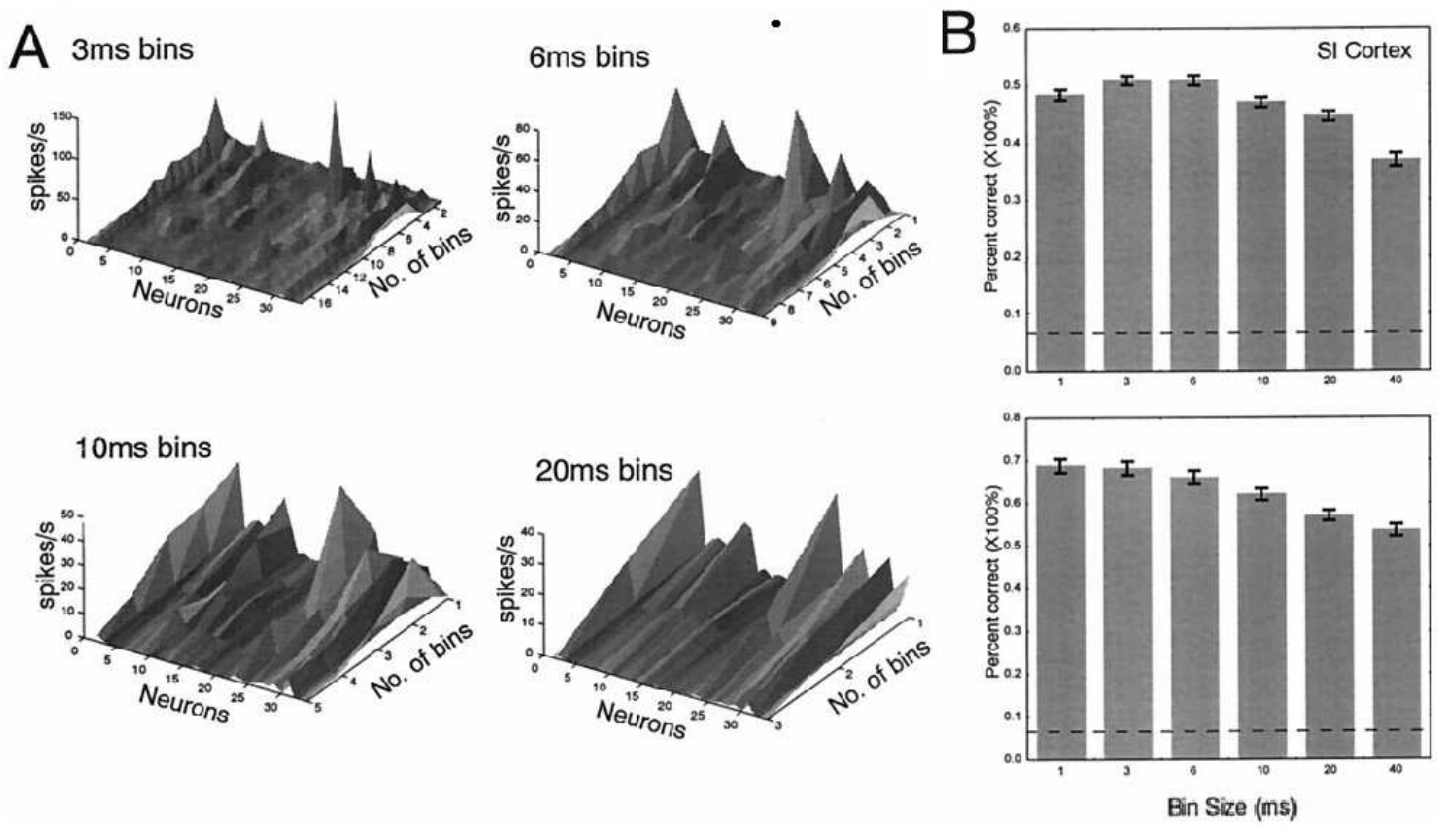
***** removal of the ***"best predictor neurons"*** does not induce sharp drops in classification performance ⇒ **thalamocortical pathway is highly distributed system (regarding encoding); despite its modular anatomical organization.**

**** # SI neurons = 2* # VPM neurons**

******* using power law to extrapolate the 99.9% level ⇒ **the ensemble size does not increase linearly with the complexity of the discrimination; this is a hallmark of distributed coding**

IV) The effect of temporal modulation of firing



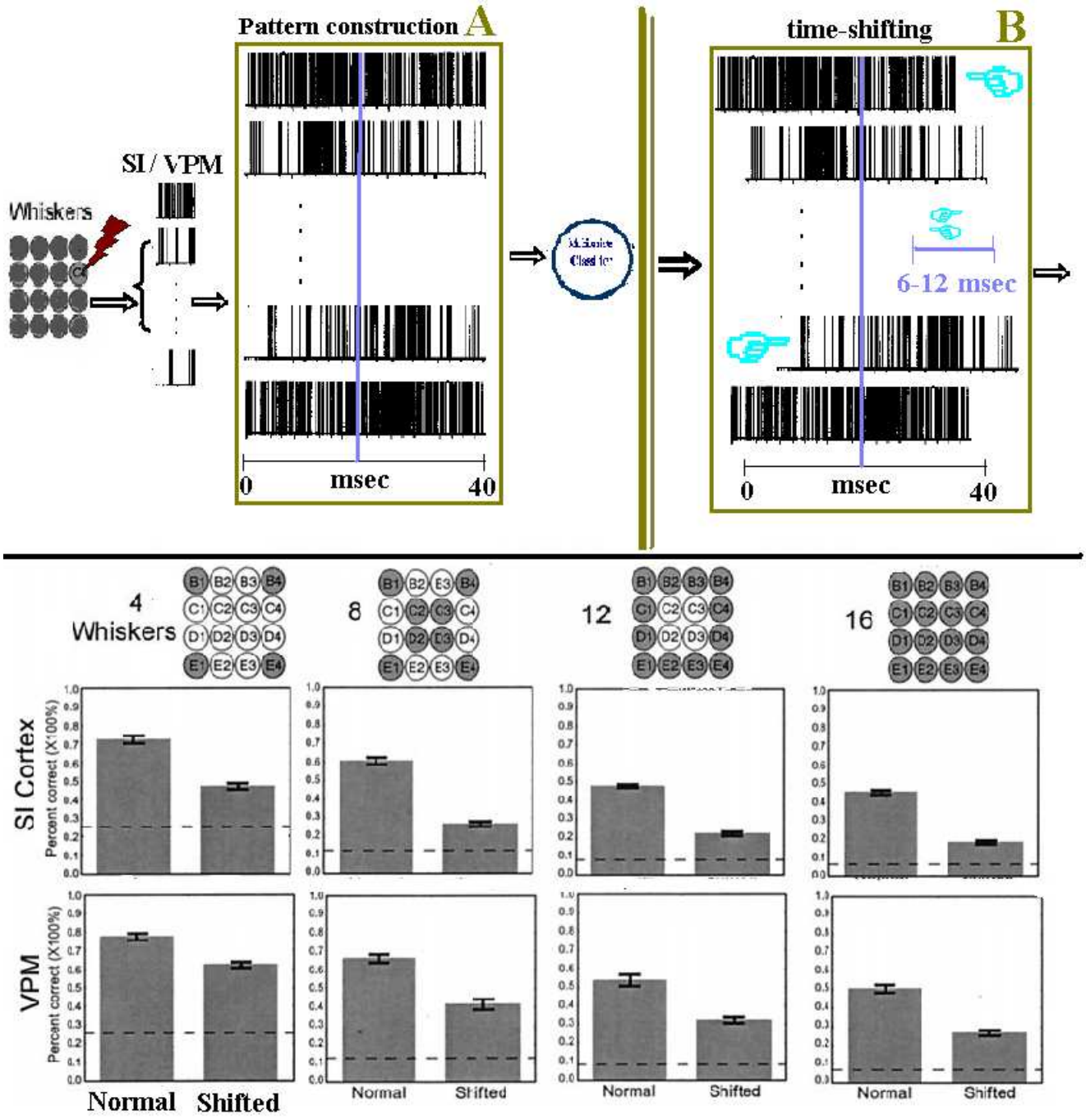


the increase in bin size ⇒ decrease in the temporal resolution of signal, but keeping intact the energy of the signal.

*** temporal modulation conveys significant information**

**** the total number of spikes contributes <u>mostly</u> to the discrimination task.**

v) The role of correlated activity among neurons



The contribution of covariance structure, within ensemble responses, to the ensemble performance was tested using
Linear Discriminant Analysis (LDA)

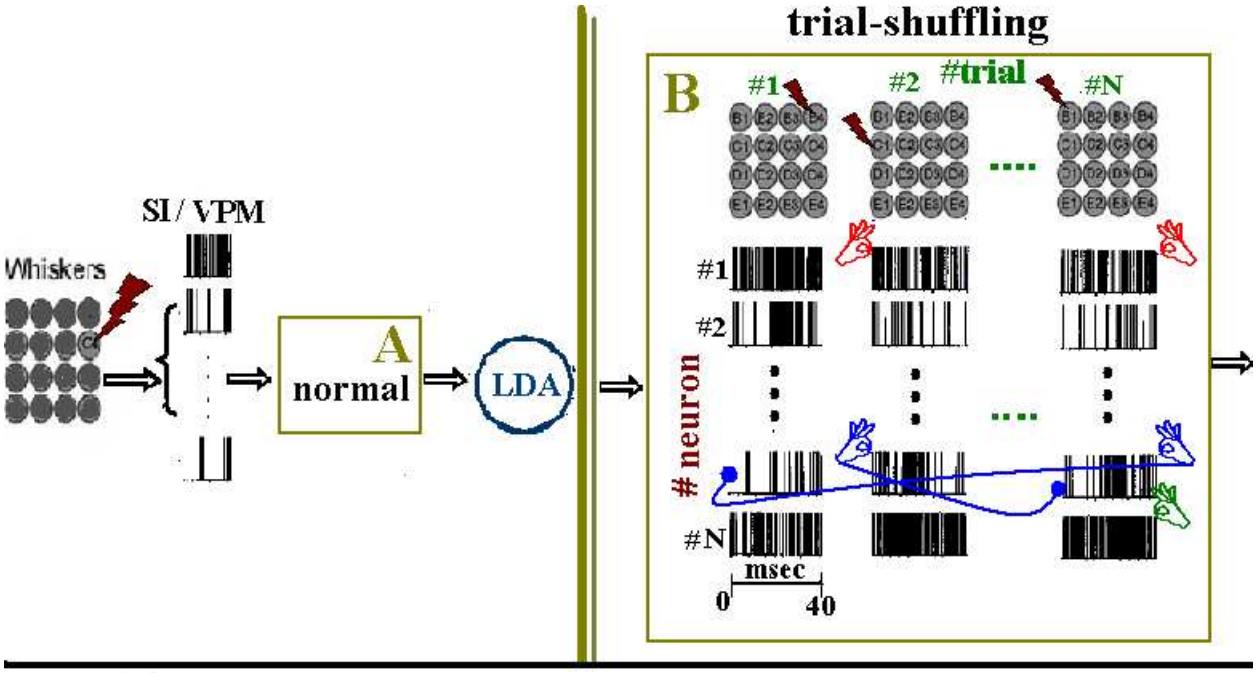
*** correlated activity disruption ⇒ significant decrease in performance**

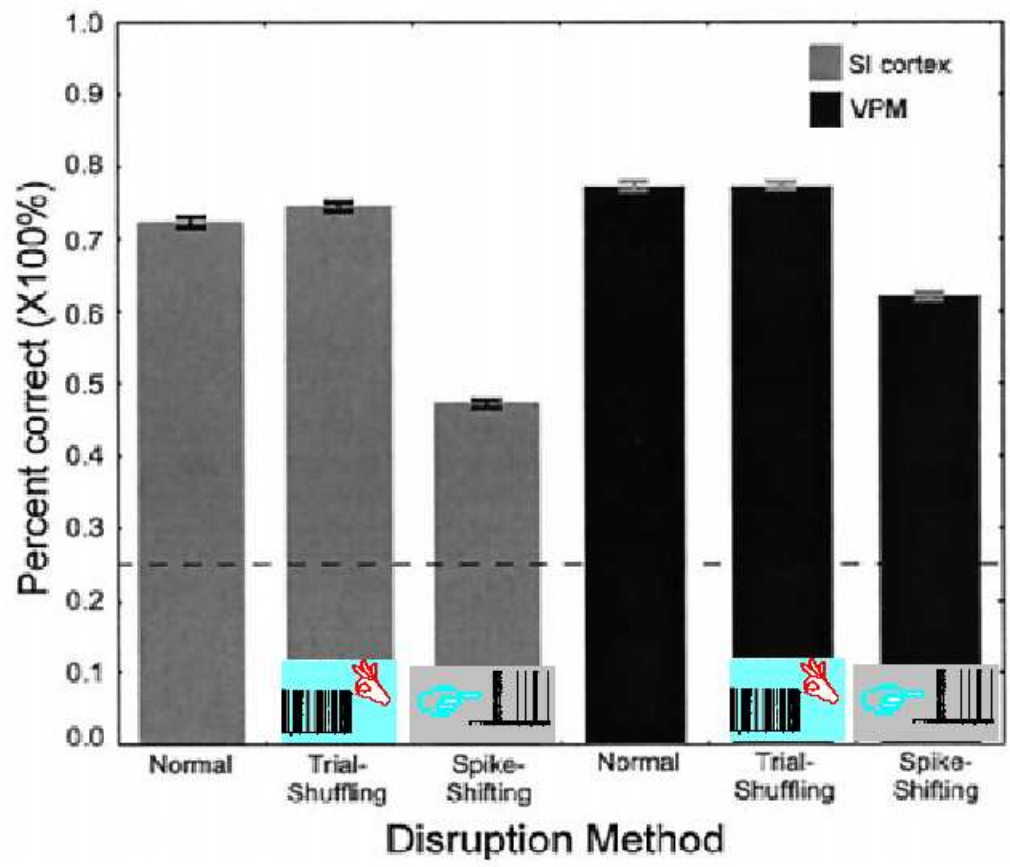
*** decrease ∝ difficulty of the discrimination**

*** correlated activity more important in SI cortex than VPM thalamus.**

VI) The role of intratrial-correlated activity among neurons

Trial shuffling: to evaluate intratrial correlated activity as a coding strategy



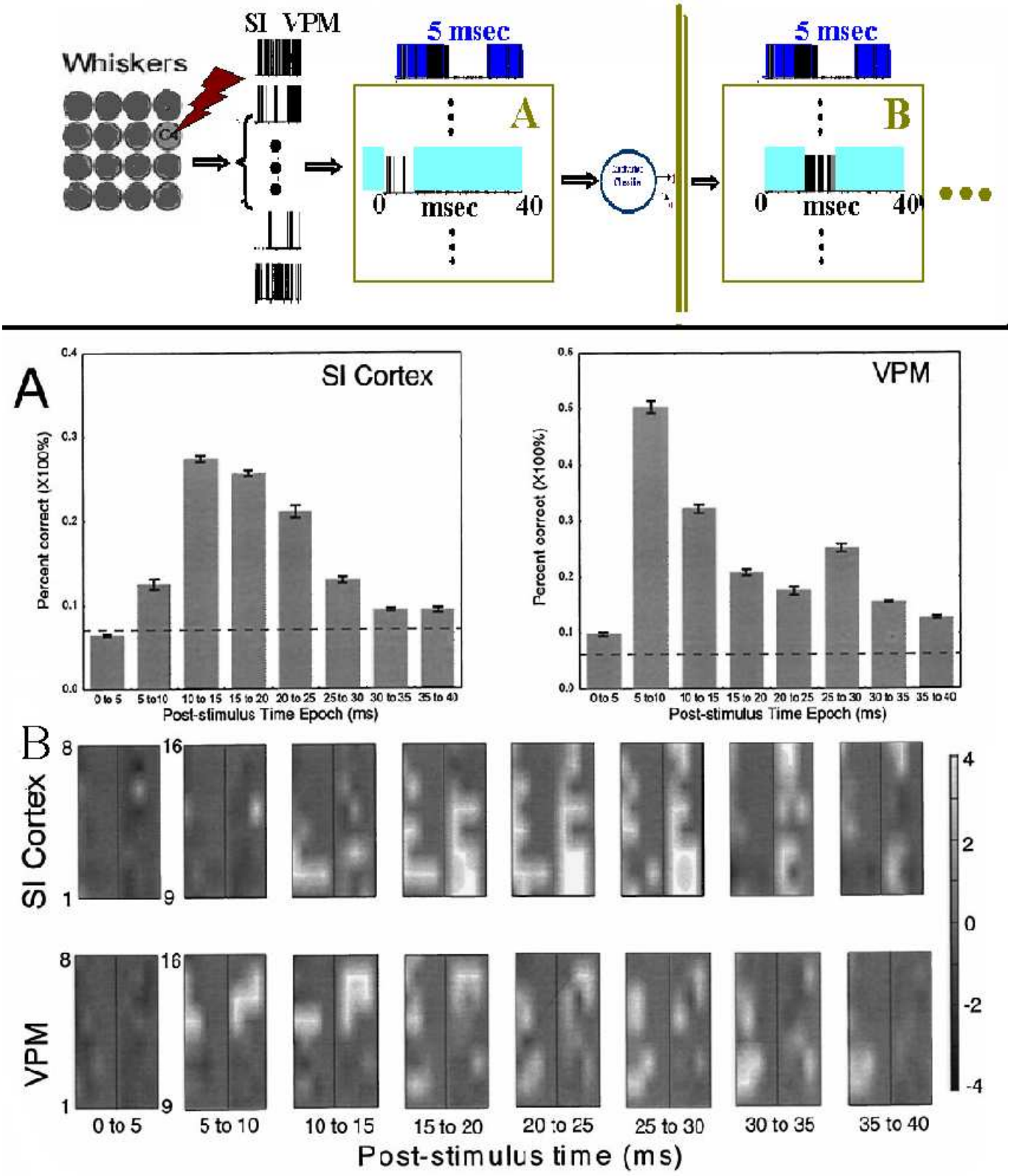


*** since trial-shuffling much less important that spike-shifting ⇒**

<u>temporal relationships</u> between spike trains within the ensemble response play a significant role.

VII) Temporal evolution of ensemble performance

The temporal modulation of the responses, over poststimulus time was investigated applying time window on the spike trains and quantifing the classification performance at certain time steps.

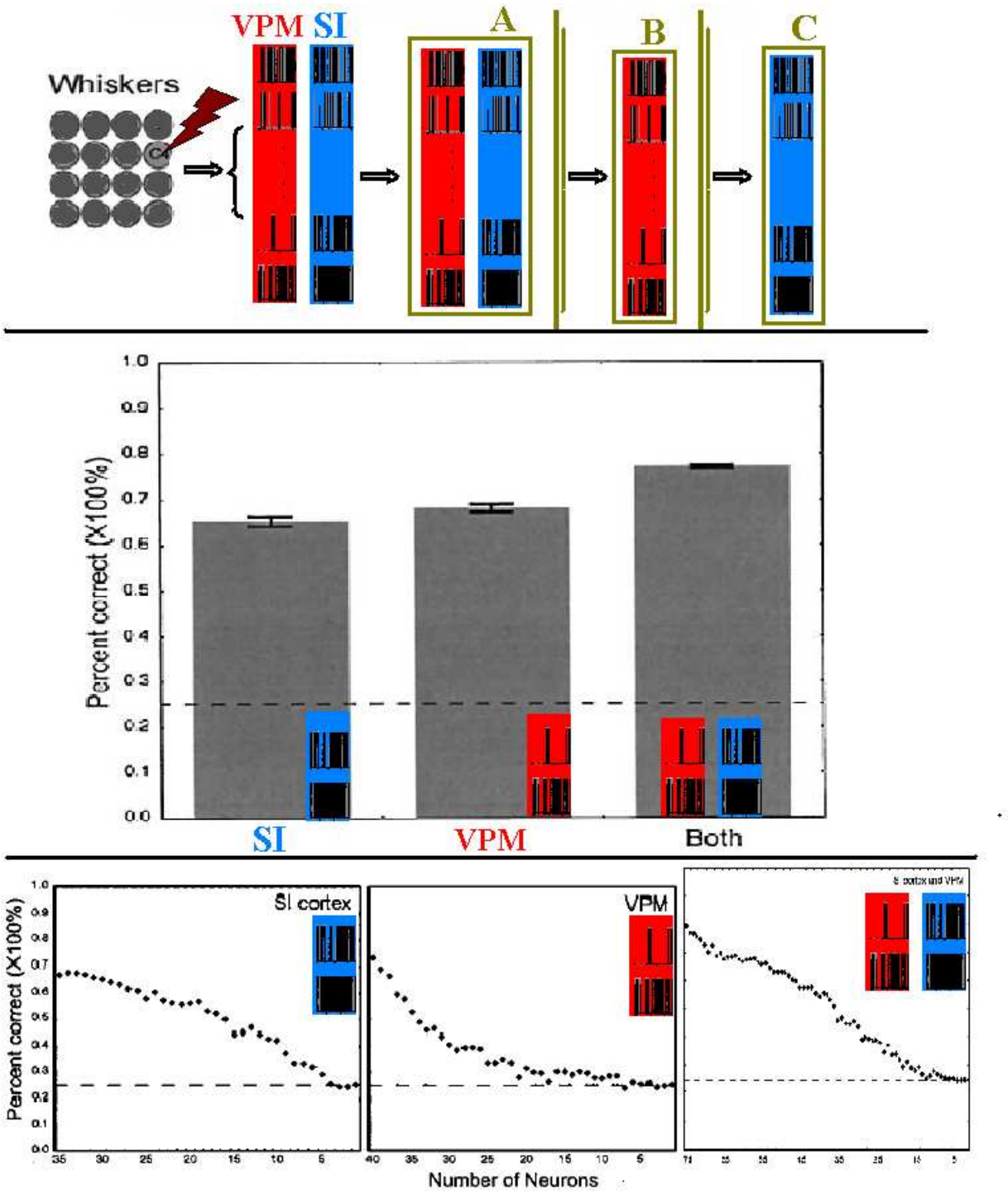


*** VPM coding is bimodal**

**** the time course of the classification performance & of the activations (PSTHs) suggest reverberatory activity between SI & VPM**

VIII) Discrimination performance of simultaneously recorded SI & PVM

The interactions between SI & VP ensembles were tested with the data from 3 rats



***the performance when neurons from both SI and VPM are utilized does not increase additively ⇒ redundancy in the encoded information**

****extrapolating the individual degradation curves so as to achieve the same performance with the overall sample (SI & VPM), results to 35% fewer neurons than the actually recorded number.**

Conclusions

- "Despite the precise topographic arrangement of modules along the rat trigeminal somatosensory pathway, this sensory system does not appear to restrict its encoding repertoire to a local coding scheme"

- "A distributed coding scheme is used by this system to compute the location of a tactile stimulus on a ***single trial*** basis".

- "Sensory system uses dynamic interactions among neurons within and between brain structures, which include various coding strategies".

- "CNS may rely on different strategies
to solve the same problem :
pure firing rate coding and multiple time codes may coexist in the same ensemble"

Discussion

- Type of stimulus
- Condition of rats
- Long term modulation
- Multivariate Statistics