J. Hirnforsch. 32 (1991) 6, 735–743

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Neural interactions in the frontal cortex of a behaving monkey: signs of dependence on stimulus context and behavioral state

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With 6 Figures

(Received September 19, 1991)

Abstract: In order to gain an understanding of the processes taking place within and between neuronal assemblies, we made simultaneous recordings of spike trains from groups of up to 11 neurons in the frontal cortex of a rhesus monkey, that was trained to perform a sensorimotor behavioral task. We report here on preliminary results from correlation analysis of these neuronal activities, with special emphasis on signs of behaviorally induced modifications of neural interaction, possibly due to rapid modulations of discharge synchronization among the neurons. Our findings suggest that different functional groups of neurons may co-exist within each small volume of cortex, and that neurons may be dynamically recruited into such a group to fulfil a specific function.

Introduction

The anatomical structure and, in particular, the massive connectivity of the cerebral cortex suggest that neural mechanisms of sensory perception, motor behavior and sensory-motor coordination are most probably mediated by interactions among cells in large neural networks (BRAITENBERG and SCHÜZ 1991). HEBB (1949) was the first to explicitly put forward the hypothesis that functional groups of neurons (*cell assemblies*) are formed by enhancement of synaptic strength in some form of associative learning process. In addition, HEBB suggested that the coherent activation of such cell assemblies forms the basis of the central neural code. The notion of synaptic plasticity in connection to an associative learning process (which later came to be known as HEBB's rule) aroused a great deal of interest among theoreticians and experimentalists alike. Nevertheless, it was only recently that direct experimental evidence (based on intracellular recordings from *in vitro* preparations) for such synaptic modification could be obtained (KELSO et al. 1986, GUSTAFSSON et al. 1987, BONHOEFFER et al. 1989, 1990). HEBB's second hypothesis, concerning the functional role of cell assemblies in central representations, was adopted widely among theoretically inclined researches. In fact, it lay the conceptual foundation for most of the current work on so-called 'neural network theories[1]' of brain function (e.g. PALM 1982, PALM and AERTSEN 1986, RUMELHART et al. 1986, AMIT 1989). However, there are very little experimental data that challenge the cell assemblies hypothesis. Neither the studies of the overall activity in large populations of neurons, nor the recording of single neuron activity allow for a critical test of the assembly concept. In order to gain an understanding of the processes within and between hypothetical neuronal assemblies, it is necessary to observe simultaneously and separably the activities of many neurons in awake, behaving animals, and to analyze these activities for possible signs of (dynamic) interactions (GERSTEIN et al. 1989).

In recent years there has been a growing interest in the simultaneous recording and analysis of spike trains from groups of up to some 10–30 neurons (ABELES 1982a, 1991, GERSTEIN et al. 1983, KRÜGER 1983, EGGERMONT 1990). However, there are still very few studies in wich recording of multiple single neurons were obtained from behaving animals. We report here on preliminary results from correlation analysis of multineuron recordings from the frontal cortex of a rhesus monkey, that was trained to perform a sensorimotor behavioral task. A large number of microelectrode recording studies in the frontal cortex have suggested that single neuron activity in frontal areas is related to sensory, motor and cognitive processes, in particular to the sensory guidance of movements (e.g. FUSTER 1973, 1989, WEINRICH and WISE 1982, EVARTS et al. 1984, WISE and MAURITZ 1985, WATANABE 1986a, 1986b, GOLDMAN-RAKIC 1987, VAADIA et al. 1988). Such activity was observed in different sub-areas of prefrontal and premotor regions. In a previous study it was reported that some neurons in the vicinity of the arcuate sulcus

1 Vortrag auf dem LEOPOLDINA Meeting „Neuronale Struktur des Neocortex" (Wiss. Leitg.: H. van der Loos u. E. WINKELMANN) Halle/S. Okt. 1990.

were activated by either auditory or visual stimuli when the animal had to attend to the location of the stimulus and make a limb movement in that direction (VAADIA et al. 1986). Thus, these various studies provided important evidence as to where and when certain processes take place. At the same time, however, they shed little light on the nature of the underlying neural mechanisms. The present study was undertaken with the purpose of improving our understanding of these mechanisms.

Methods

Rhesus monkeys were trained to perform a sensorimotor behavioral task with two paradigms. In the '*localizing*' paradigm, about 1—1.5 s after the beginning of a trial (INIT, cf. Fig. 1), two spatial cues (S1 and S2) of different modalities (auditory and visual) were presented sequentially (interstimulus interval 1—1.5 s) from two different locations. Again 1—1.5 s later, a GO-signal was presented, informing the monkey by a color code which of the two stimuli was the relevant directional cue. The reinforced response was an arm movement in the direction of that cue. In the second paradigm ('*non-localizing*'), the same sequence of stimuli (INIT, S1, S2, and GO) was presented in the same pattern as in the first task paradigm. In this case, however, the reinforced response was a movement to a fixed target, disregarding the directional information in the cues and in the GO signal. Both paradigms were used intermittently.

After the monkey had been trained, daily recording sessions began. In each session the activity of several neurons was recorded simultaneously by 6 metal microelectrodes, that were inserted into the frontal cortex by an apparatus of 6 microdrives. In combination with a number of spike sorting devices that could be switched to any of the electrodes, this enabled to record from up to 11 different neurons at a time. A more detailed account of the experiment protocol and the various experimental techniques has been given elsewhere (VAADIA et al. 1989, 1991).

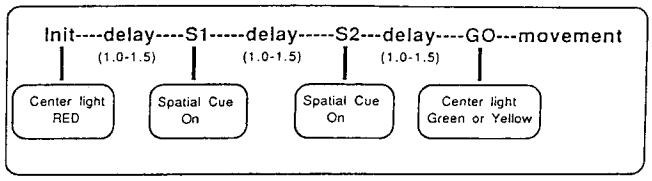

Fig. 1. The sequence of events from trial initiation to the behavioral response in the localizing task.

Results

The activity of about 750 neurons in the frontal cortex was recorded. The recording area encompassed premotor and prefrontal areas around the superior limb and the genu of the arcuate sulcus and near the posterior end of the principal sulcus.

Single Neuron Activity in Relation to Behavioral Events

The analysis of single neuron activity indicated that in the frontal cortex neurons exist which elevate their firing rate selectively when the animal has to perceive the location of stimuli and plan movements towards that location. Figure 2 shows raster displays of the activity of nine

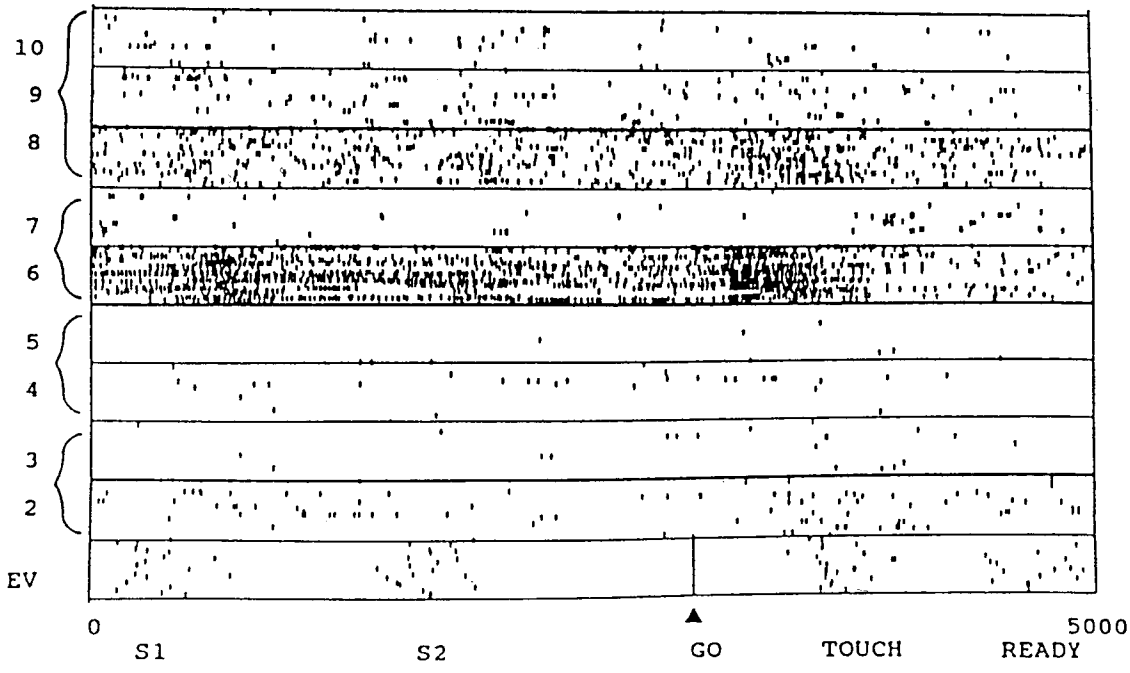

Fig. 2. Raster display of the activities of nine neurons in the frontal cortex of a monkey during performance of the 'delayed localizing task'. The displays are plotted from 3 s before the GO signal (marked by a triangle at the bottom) until 2 s after it. The activity was collected from correct trials, in which the auditory spatial cues were presented in the left hemifield at 15° from the midline. Several events are marked in the bottom window (EV; compare Fig. 1): onset of the first spatial cue (cluster of dots above S1), onset of the second spatial cue (S2), onset of the GO signal (vertical line across the window above the triangle), the time when the monkey hit the target ('touch'), and the time when the monkey was ready for the next trial ('ready'). The units were recorded by four microelectrodes; the first picked up units 2—3, the second: units 4—5, the third: units 6—7, and the last: units 8—10. Notice the task-related activity of units 6 and 8, while their neighboring units were practically unaffected by behavioral events.

neurons, recorded simultaneously during the performance of the localizing paradigm. Those trials were selected in which the relevant spatial cue was an auditory stimulus at 15° in the contra-lateral hemifield. Each of the upper nine strips represents the activity of one neuron. Behavioral events are displayed in the lower strip (EV); the vertical line marks the onset of the GO-signal. The nine neurons were recorded by four microelectrodes; units 6 and 7 were recorded by one electrode, units 8, 9, and 10 by another one. Observe that the firing rates of units 6 and 8 were clearly affected by the GO-signal during performance of the task, while other neurons, even neighboring ones recorded by the same microelectrode, were not affected at all. Notice also that the firing rates of the task-related neurons in Fig. 2 was increased after the GO-signal, when the monkey was performing the localizing task and responding by making limb movements to touch a key at 15° on the left. These some neurons, however, were almost unaffected by the GO-signal when the monkey made other movements, or when the same movements were made during performance of the non-localizing task (not shown here). Thus, neurons 6 and 8 showed similar directional selectivity and behavioral dependence.

This pattern was found to repeat at many other recording sites: (1) task-related, neighboring units were activated under similar conditions, but could also have separate or different response patterns, and (2) task-related neurons intermingled with many non-responsive neurons. Based on these and similar results (VAADIA et al. 1989, 1991), we hypothesize that the functional organization of each small volume of cortex allows for the coexistence of functionally distinct neurons, which may participate in several different processes.

Interactions between Simultaneously Recorded Neurons

In order to assess the extent to which neurons with similar task-related properties organize into functional groups, we analyzed the interactions taking place between these neurons. The common technique to examine such interactions is to construct a cross-correlogram, describing the firing probability of one neuron as a function of the time that elapsed after a spike occurred in the other one (PERKEL et al. 1967). We describe here the results of such cross-correlation analysis of neuronal activity recorded during performance of a behavioral task, as well as during 'non-performance' periods, i.e. when no stimuli were delivered and the monkey did not perform the task.

Figure 3 illustrates different types of cross-correlograms obtained from pairs of neurons in the frontal cortex during 'non-performance' periods. Fig. 3a shows an example of *uncorrelated* activity: the firing probability of the first cell did not change significantly before or after the firing of the other. About 30% of the neuron pairs recorded from the same microelectrode showed such uncorrelated activity (VAADIA et al. 1991). In some cases

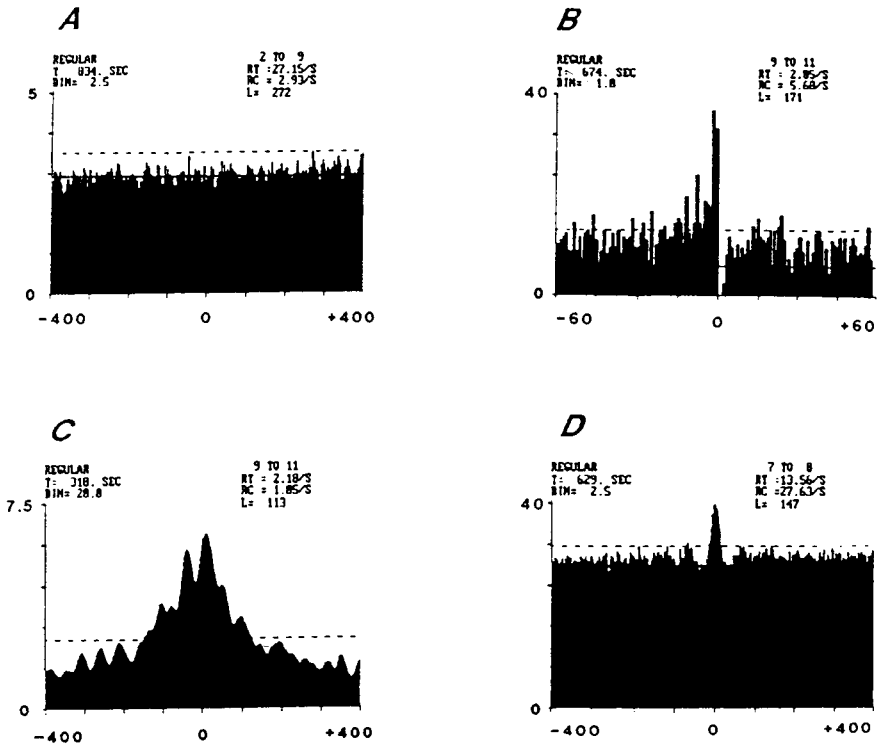

Fig. 3. Cross-correlograms between pairs of cortical neurons. The abscissa describes the time (ms) around the firing of one neuron, and the ordinate describes the firing rate of the other neuron in spikes/s. The labels on each correlogram give the total data collection time (T), the average firing rate of the two neurons (RT and RC), the bin size (BIN) and the number of data sections (L). For each correlation, a band of 99% confidence limits for the equivalent, independent Poisson processes (ABELES 1982b) is shown by broken lines. A: Uncorrelated activity; B: One-sided, narrow peak (note the different time scale in this case: −60 to +60 ms); C: Two-sided, wide peak; D: Two sided, narrow peak.

a narrow peak confined to one side of the origin could be observed (Fig. 3b). The interpretation that these correlograms reflect a so-called *direct excitatory connection* between the two neurons is supported by the finding that most of these one-sided peaks were found among neurons that were recorded by the same microelectrode, but never among neurons that were more than 600 µm apart. Signs of a *direct inhibitory connection* (a one-sided trough) were found in only very few cases. This is not surprising, however, in view of the low sensitivity of cross-correlation for inhibition under conditions of low firing rates (AERTENS and GERSTEIN 1985), as typically found in this part of the cortex (ABELES et al. 1990). In the sample of neuron pairs that were recorded by one microelectrode, signs of such 'direct connections' (excitatory and inhibitory) were found in about 20% of the cases, most of them weaker than the example in Fig. 3b (VAADIA et al. 1991). By far the most common type of interaction found (30% of all pairs; VAADIA et al. 1991) was a more or less symmetrical peak straddling the origin. This type of interaction, usually referred to as *'shared'* or *'common input'*, came in two variants, distinguished by the width of the two-sided peak: *wide* (more than 200 ms; Fig. 3c), and *narrow* (15–100 ms; Fig. 3d). Interestingly, the probability of finding 'narrow common input' decreased rapidly with the distance between the cells: according to a preliminary investigation (LAVNER 1989) such interaction was found among 30–40% of the pairs recorded by the same microelectrode, as opposed to only 3–8% of the pairs that were 500–600 µm apart. In contrast to this, the probability of finding 'wide common input' did not show a clear dependence on pair distance for distances up to 1 mm; within that range the overall frequency of occurrence was 10–20%.

More detailed analysis of the interaction between pairs of neurons is still in progress. However, already at this stage the results clearly indicate that pair interactions may depend on the behavioral state. An example of such an interaction that was modified in relation to behavior is shown in Figure 4. The spike trains of the two neurons in Fig. 4a were recorded during a 'non-performing' condition, the data in Fig. 4b were collected from sections of the inter-trial intervals (ITI; 3 seconds each) during performance of the localizing task. Direct excitatory interaction can be observed when the monkey was not performing the task, while the spike trains recorded during the inter-trial intervals show no correlation at all.

To conclude, the interactions among adjacent neurons as revealed by cross-correlation analysis were mostly of the 'two-sided', less often of the 'one-sided' type. Usually the observed correlations were weak, even among neurons that had similar functional properties. In a number of cases, the interactions among neurons could be modified on a short time scale in relation to external events or the behavioral state.

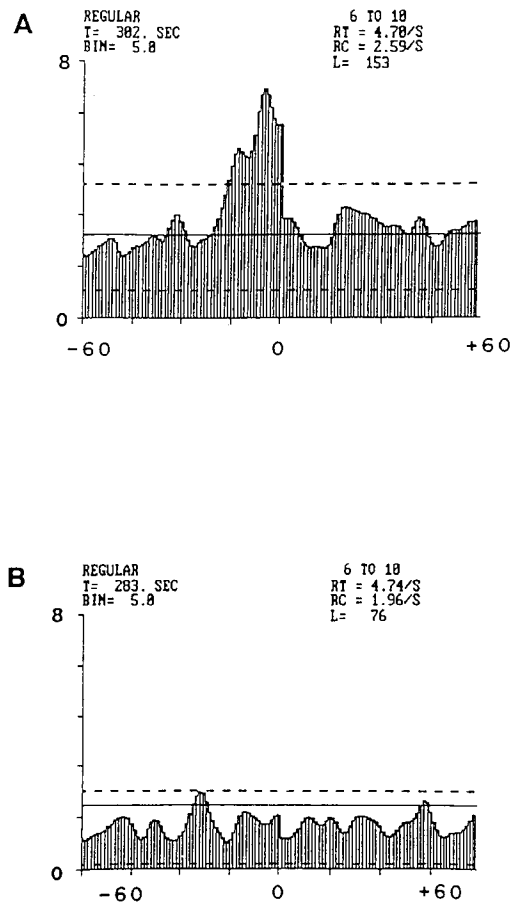

Fig. 4. Two cross-correlograms of one pair of neurons recorded in the prefrontal cortex. The cross-correlogram in A was computed from sections of 'spontaneous activity'. The cross-correlogram in B was computed from sections of 'inter-trial intervals' during performance of the localizing task. Notice the 'direct excitatory interaction' when the monkey was not performing the task, and the complete absence of correlation during the inter-trial intervals of the localizing task.

Dynamical Properties of Neuronal Interactions

It is quite conceivable that the behaviorally induced changes of interaction are due to rapid modulations of discharge synchronization among the neurons. Unfortunately, the ordinary cross-correlogram, representing a time-averaged count of near-coincident spikes, does not allow to examine the time course of such changes. Recent developments in analysis methodology, however, overcome this problem. In particular, the *Joint-PSTH* (AERTSEN et al. 1989, PALM et al. 1988) is designed to highlight the detailed time structure of firing correlation among two neurons, and its possible time-locking to a third event, such as a stimules or behavioral event. Moreover, appropriate normalization of the Joint-PSTH enables us to distinguish between contributions due to stimulus- or behavior-induced modulations of the individual neuron firing rates, and those from interneuronal correlation, the

latter reflecting the *'effective'* or *'functional connectivity'* among the neurons involved.

Figure 5 shows an example of the results of this analysis and the dynamic changes of pair interaction revealed by it. Data was collected from two different time sections of spike trains from two frontal cortex neurons during performance of the localization task. The first section comprises 600 ms immediately following the GO-signal (Fig. 5a), the second one covers an interval of 600 ms, starting 900 ms after the monkey's hand left the target key (after hitting the correct location, and the monkey received its reward) and returned to its resting position (Fig. 5b). Comparison of the normalized Joint-PST histograms in both panels reveals considerable differences in the interaction patterns among the neurons, both in the time-averaged correlograms and, even more so, in their detailed time course displayed along the diagonal. Following the GO-signal (Fig. 5a), the time-averaged correlation is characterized by a strong, 'bi-phasic' interaction pattern: a narrow peak for negative delays, accompanied by a wider trough for positive delays. Interestingly, the positive peak does not reflect an ongoing and stable interaction, but is the net result of two extremely short-lasting instances of discharge synchronization, occurring in coincidence with the onset and offset of firing of one of the two neurons (compare the PSTH along the y-axis), with no interaction whatsoever outside these two short intervals. Similarly, the negative interaction changes dramatically as time proceeds. The time tourse of modulation, however, is quite different: a sharply increasing and gradually decaying negativity, with the dominant contribution originating from the onset phase of the first neuron, shortly after the first peak of positive interaction, when also the second neuron (PSTH along the x-axis) elevates its firing rate. During the second time section, however, separated from the first one by a mere 1.5 s, these same two neurons exhibit a completely different type of correlation (Fig. 5b). In contrast to the earlier result, the overall interaction now is characterized by an asymmetric, damped oscillator type correlation, with the main peak straddling the origin. Again, inspection of the diagonal region reveals distinct signs of dynamic modulation of the interaction. Although in this case the increased noise level (presumably due to the considerable reduction in firing rates of both neurons) prohibits an unequivocal parsing into separate components, there are hints of two nonoverlapping oscillatory subpatterns (extending roughly from 900—1100 ms and from 1200—1400 ms), possibly associated with concurrent features in the firing rate of one of the neurons (compare the PSTH along the x-axis).

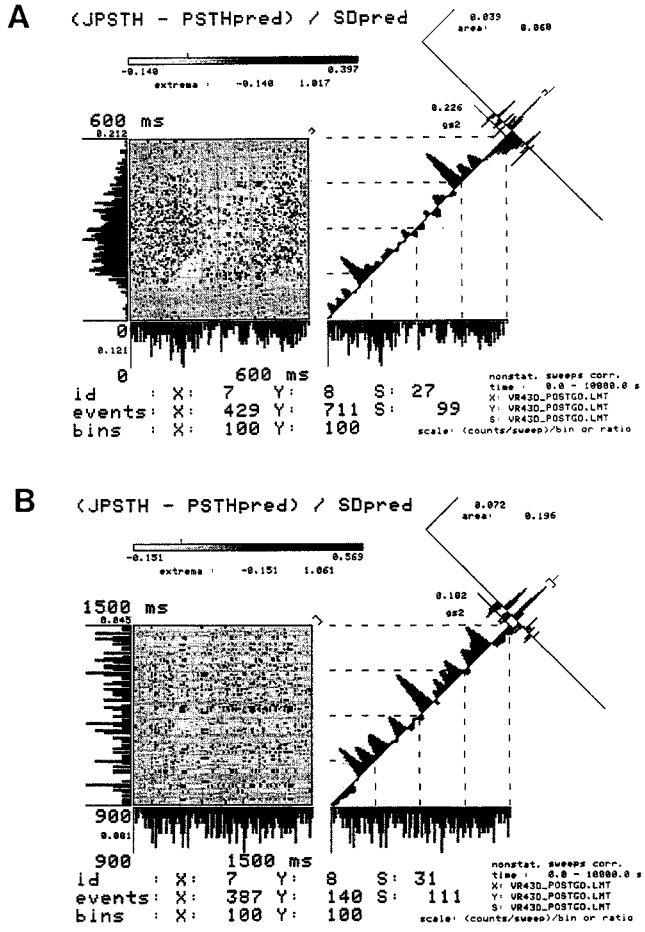

Fig. 5. Joint-PSTH analysis of two simultaneously recorded neurons from the frontal cortex of a monkey during performance of the 'delayed localizing task'. The grey-coded, normalized Joint-PSTH matrices in both panels represent the time-dependent correlation of firing among the two neurons, after normalization for stimulus-induced modulations in single neuron firing rates. The latter are assessed by the PST-histograms shown along the horizontal and vertical axes. The diagonal band of the normalized Joint-PSTH matrix reflects the near-coincident firing correlation as it evolves in the course of time; it is shown once again in the diagonal histogram in the right-hand part of the Figures (lower left to upper right). Finally, the normalized cross-correlogram is obtained by integrating along the diagonal; it is shown in the second histogram in the right-hand part of the Figures (upper left to lower right). Data was collected from two different time sections of spike trains: A. Time section of 600 ms immediately following the GO-signal; B. Interval of 600 ms, starting 900 ms after the monkey's hand left the target key (after hitting the correct location, and the monkey received its reward) and returned to its resting position. Notice the clear differences in correlation during these two time sections, separated from each other by only about 1.5 s. Further explanation in text.

This example clearly demonstrates that the neurons' activities may exhibit rapid modulations of discharge synchronization that are related to the behavioral state. These modulations may switch the neurons' firing behaviour from being mutually incoherent into a particular coherent state of joint synchrony, or, alternatively, from one particular pattern of mutual coherence into a different one. Each such pattern may last for only a few tens to hundreds of milliseconds. Finally, the observed modulations in synchronized firing may be, but are not necessarily associated with changes in either of the neurons' individual firing rates.

Interactions among Larger Groups of Neurons

So far we only addressed the issue of correlation between two neurons at a time. An important question in view of the hypothesis that neurons dynamically organise into functional groups, is whether correlations also exist between larger groups of neurons, and, if so, whether such group correlations follow a similar pattern as the pair correlations do, particularly regarding their dependence on behavioral state. In order to study the global firing correlations among entire groups of simultaneously recorded neurons, we used the *gravitational clustering* analysis (GERSTEIN et al. 1985, GERSTEIN and AERTSEN 1985, AERTSEN et al. 1986, 1987). This recently developed conceptual framework and analysis technique was explicitly designed to deal with population activity, in particular for the detection of co-activation of larger numbers of neurons. We give here only a brief description and refer to the original literature for more details.

Suppose we measure spike trains from N neurons. Each one of these N neurons is represented by a point particle in a fictitious N-space. To each such particle, we associate a time-varying 'charge', determined by the respective neuron's spike train. As a result, the particles will mutually exert forces that cause them to 'move'. The charge functions are defined such that the forces lead to aggregation of those particles which correspond to coherently firing neurons, with each single cluster signifying the member neurons of a particular cell assembly. The time dependence of clustering conveys information on the static ('strength') as well as the dynamic aspects of coherent activity. The resulting configurations can be

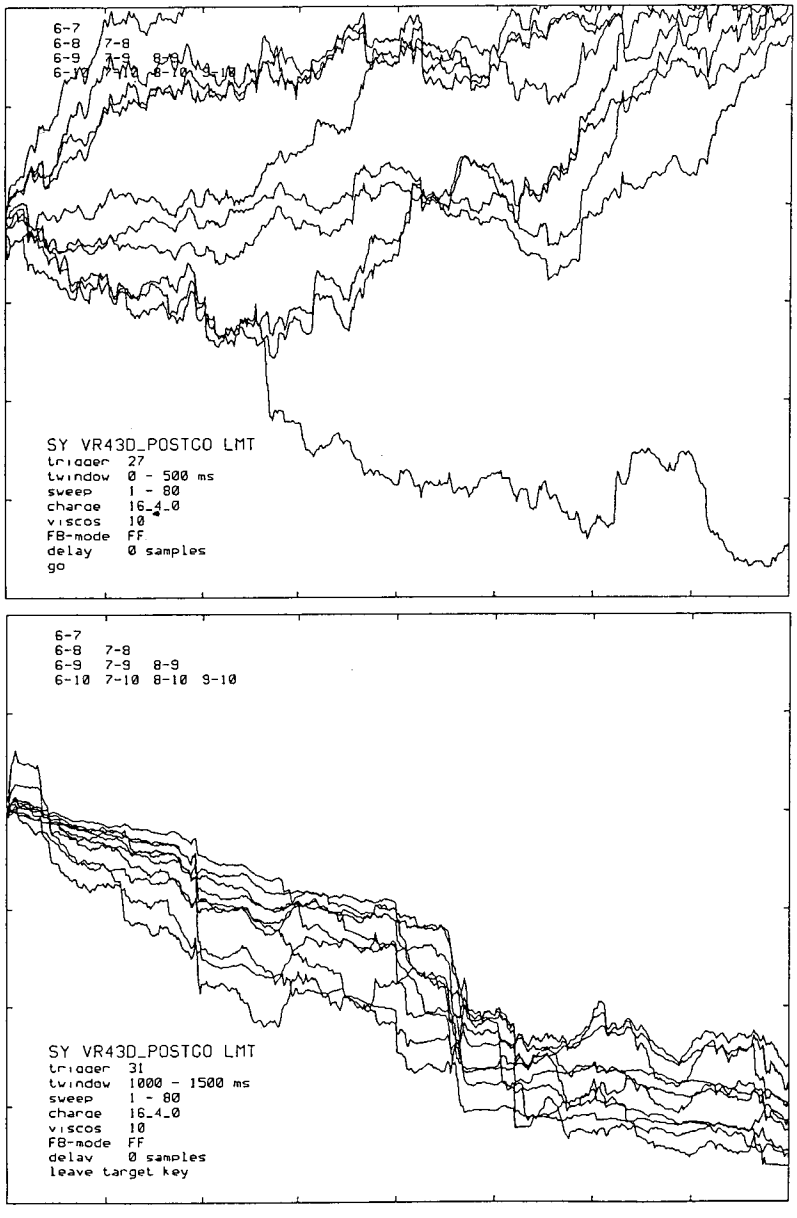

Fig. 6. 'Gravitational Clustering' analysis of correlation among multiple single-neuron activity in the frontal cortex of a monkey during performance of the 'delayed localizing task'. Each set of curves represents the group correlations during a particular sequence of 0.5 second long intervals of spike activity, parsed from a single recording session, the difference being that the first series of intervals (upper panel) was time-locked to the GO-signal, while the second series (lower panel) was time-locked to the behavioral event of the monkey leaving the target key. Clearly the clustering patterns and, hence, the organization of correlation are distinctly different in these two cases, showing that correlations among groups of neurons in frontal cortex may be altered drastically and in rapid succession, depending on the stimulus context and behavioral state of the animal. Further explanation in text.

investigated directly by resorting to high-dimensional cluster analysis techniques, or visually, by appropriate projection of the N-space onto a more convenient 2-space representation. If cell assemblies are dynamic entities, related to stimulus context or behavioral state, the particles associated with the member neurons of such an assembly would aggregate during the stage which calls the assembly to action, and move away from each other to regroup in different clusters, when other assemblies are called upon the stage.

Preliminary results from gravitational analysis of frontal cortex recordings indicate that (a) global correlations among larger groups of neurons in frontal cortex do exist, and that (b) these group correlations may indeed be altered drastically and in rapid succession, depending on the stimulus context and behavioral state of the animal. An example of such group correlation and its behavioral dependence is given in Figure 6. The plots show the pairwise inter-particle distance in the gravitational representation as a function of time, with each single curve representing the firing correlation among a particular pair in the set of simultaneously recorded neurons. The temporal development of clustering is signified by a downward slope of some of the curves: the larger the downward slope, the stronger the positive correlation (and upward for negative correlation). The two panels represent the firing correlations among five well isolated single frontal cortex neurons, recorded simulteously during performance of the localization task. Each of the two panels corresponds to a particular sequence of 0.5 second time intervals of spike activity that were collected from a single recording session. The two panels differ in that the respective time sections were time-locked to different stimulus or behavioral events: similarly to the results in Figure 5, the top panel describes the correlations during the 0.5 second immediately following the GO-signal, while the bottom panel covers the interval between 1 and 1.5 second after the monkey's hand left the target key to return to its resting position. Observe how the clustering patterns (and hence, the group correlations) are distinctly different in these two cases. Following the GO-signal (top), only one pair of neurons shows positive correlation (the single descending curve), whereas the remaining particles either remain noisily stationary (i.e. no correlation between the corresponding neurons) or have even a weak tendency to diverge, suggesting a negative correlation. In contrast, during the return movement (bottom) *all* curves exhibit a strongly similar descent, indicating a collective aggregation into a single cluster. Evidently, during this second interval *all* five neurons temporarily join into a common mode of coherent firing; further analysis (not shown here) reveals that both immediately before and after this particular 0.5 second interval, this collective behavior is very much weaker or altogether absent. It should be born in mind that the selected time sections were separated on the average by only about 1—1.5 second, so that indeed this change of correlation is a very rapid one.

These and similar results (AERTSEN and GERSTEIN 1991, VAADIA et al. 1991) imply that the observed changes in correlation are not simply due to task-related changes in single neuron firing rates, but rather reflect interesting, task-related and highly dynamic changes of interaction among these neurons. We stress that the changes in assembly organization, signified by these changes in firing correlation, could not have been revealed by any single unit analysis of the individual neurons involved.

Discussion

At present, we have concluded only part of the data analysis. Nevertheless, the results obtained so far confirm that our approach of simultaneously recording from several neurons in a behaving animal, even if still limited, provides exciting new insights into the neural mechanism of higher brain function. The analysis of single neuron activity revealed that neighboring neurons in the frontal cortex may be functionally related and share common features. However, even when neurons were recorded by the same microelectrode, they were not all activated in unison. The results of correlation analysis indicate that the interactions between neurons may depend on the stimulus context and/or behavioral state. Moreover, it appears that the interactions among neurons may be highly dynamic, with time constants of modulation as low as tens of milliseconds. These examples of rapid, task-related changes of correlation in the frontal cortex were found without an extensive search through the available data. Further analysis into their relative frequency and distribution among the various stimulus and behavioral events is obviously necessary in order to assess their functional role in the neuronal mechanisms subserving dynamical changes of sensorimotor associations.

Our observations support the hypothesis that the neural code for higher brain function resides in the activity of groups of neurons. Our findings further suggest that these 'neuronal groups' are dynamic entities, defined not only by anatomical connections, but also by the everchanging level of correlation among the activities of their member neurons. Considering that a neuron in the cortex makes contacts with thousands of other cells (BRAITENBERG and SCHÜZ 1991), it becomes evident that when such a neuron is momentarily coactivated with one set of cells, part of its connections will become effective for a corresponding brief period of time. However, when some time later, due to a change in stimulus context or behavioral state, the same cell is co-activated with another set of neurons, a partly or even altogether different subset of its connections will become effective. Thus, there is no need for the synaptic contacts to be particularly strong:

the corresponding connections become effective through synchronous activity with other neurons (ABELES 1982a, 1991). Computer simulations (ERB et al. 1986, 1989, 1990) and analytical calculations (AERTSEN and PREISSL 1991) on artificial neural networks with various types of architectures have demonstrated that considerable and rapid changes in effective connectivity may, in fact, occur without any associated changes in anatomical connectivity. Rather, such changes in effective connectivity may be a reflection of the dynamics of the activity in the entire network, both regarding the rates (BOVEN and AERTSEN 1990) and the internal coherence (BEDENBAUGH et al. 1988, 1990) of firing. Thus, the highly dynamic interplay of activity and connectivity in the cortex gives rise to an ongoing process of functional reorganization. Everchanging groups of neurons, each one recruited for brief periods of time, become co-activated and again de-activated, following each other in rapid succession. It is our conjecture that this dynamic reorganization provides the mechanism which underlies our capacity to rapidly change our sensory perceptions, motor behaviour and sensori-motor associations.

Acknowledgements

The results reported in this paper are based on experiments and analysis performed in the Dept. of Physiology at the Hebrew University in Jerusalem, and on additional analysis carried out at the Max-Planck-Institut für biologische Kypernetik in Tübingen. In the context of this joint research project, one of the authors (AA) spent the year 1990–91 on sabbatical leave in the Dept. of Physiology at the Hebrew University; he wishes to thank Prof. Moshe ABELES and his team for their kind hospitality, and the Lady Davis Foundation and the Minerva Foundation for their generous support.

This research was supported by the Israel Academy of Sciences and Humanities, the Charles A. Revson Foundation, the German Ministry for Science and Technology (BMFT), the Graduiertenkolleg Neurobiologie Tübingen, and the German-Israel Foundation for Research and Development (GIF).

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J. Hirnforsch. 32 (1991) 6, 744

Buchbesprechungen

J. Langman

Medizinische Embryologie

8. überarbeitete Auflage
Verlag Georg Thieme
Stuttgart–New York 1989
ISBN 3-13-446008-2

Der 8. deutschen Auflage der „Medizinischen Embryologie" von J. Langman liegt die 4. Auflage der „Medical Embryology" zugrunde, für deren Übersetzung ins Deutsche in bewährter Weise U. Drews verantwortlich zeichnet.

Die vorliegende 8. Auflage weicht in ihrem Aufbau nicht von den vorhergehenden Auflagen ab, ist aber noch stärker auf Übersichtlichkeit sowie klare und deutlich gegliederte Darstellung des Lehrstoffes ausgerichtet. Damit dürfte das Buch den Bedürfnissen besonders der Medizinstudenten wiederum entgegenkommen. Die den einzelnen Kapiteln angefügten, deutlich gekennzeichneten Zusammenfassungen erleichtern dem Studenten nicht nur die Überprüfung des eigenen Wissens, sondern erlauben auch eine schnelle Rekapitulation des gesamten Stoffes. Ebenso sind die Beziehungen zur Fehlbildungslehre im Text stärker herausgehoben. Zu den Abbildungen ist zu sagen, daß sich der „Langman" wie immer schon durch seine zahlreichen, sehr instruktiven Skizzen zum Entwicklungsgeschehen auszeichnet.

Sicher gibt es Themenkomplexe, bei denen heute noch andere Auffassungen zur Entwicklung vertreten werden. Ein solcher Komplex ist z. B. die Herzentstehung, für die zumindest beim Menschen nicht mehr von einer paarigen Anlage in der kardiogenen Zone ausgegangen wird, sondern bereits von Anfang an von der Bildung eines medianen, **unpaaren** Lumens, das aus dem Zusammenschluß vieler Blutinseln hervorgeht. Sicher ist die Entwicklung der herznahen Gefäße ebenfalls ein Thema, bei dem unterschiedliche Auffassungen vertreten werden können. Auch wenn beim Menschen niemals 6 Paare von Schlundbogenarterien gleichzeitig angelegt werden (wie auf Seite 227 ausgeführt), hat doch deren schematische Darstellung (Abb. 12–35) den großen Vorzug, die Entwicklung der herznahen Gefäße dem Studenten **verständlich** zu machen. Unter dieser Voraussetzung sollte z. B. auch der Nachweis, daß eine 5. Schlundbogenarterie (Pharyngealarterie) keine „echte" Schlundbogenarterie ist, später als die 6. entsteht und nur sehr kurz nachweisbar ist, bei der Kompliziertheit der Bildung der herznahen Gefäße dem Verständnis, jedenfalls für Studenten, untergeordnet werden. Daß Eigennamen bestimmter Gefäßabschnitte in diesem Gebiet, wie etwa des Ductus Botalli, als nicht mehr gerechtfertigt gelten können, geht aus dem Langman-Text hervor, indem diese Eigennamen nur noch im Sachwortregister nachgewiesen sind.

Unterschiede in den Auffassungen zur Entwicklung bestimmter Organsysteme, wie sie z. B. für die Pankreasanlage, für das dorsale und ventrale Mesenterium, für die Bursa omentalis, bestimmte Teile der Gesichtsentwicklung usw. vertreten werden, lassen sich in einem so konzipierten Lehrbuch nicht in Einzelheiten darlegen, ohne dessen Rahmen zu sprengen.

Ohne Zweifel wird diese 8. überarbeitete deutsche Auflage der „Medizinischen Embryologie" Langmans, nicht zuletzt dank der sorgfältigen Arbeit des für die deutsche Ausgabe verantwortlichen Herausgebers H. Drews (u. a. neubearbeiteter Schlüssel zum Gegenstandskatalog für die medizinische Vorprüfung!), den Studenten der Medizin, aber auch all denen, die embryologische Fragestellungen kurz rekapitulieren möchten, eine große Hilfe sein.

Thomas Schuster, Berlin

H.-J. Kretschmann, W. Weinrich

Klinische Neuroanatomie und kranielle Bilddiagnostik

1991. VIII, 372 Seiten mit 596 meist mehrfarbigen Einzelabbildungen, Geb. DM 348,–
ISBN 3-13-615202-6
G. Thieme Verlag Stuttgart, New York

Der vorliegenden 2. Auflage des Buches sind zwischenzeitlich nach der 1. Auflage 1984 je eine 1. englische und eine 1. japanische 1986, eine 1. spanische 1988 und 1989 eine 1. italienische Auflage erschienen.

Diese Empfehlung spricht für sich! Es bleibt die Frage, worauf sich der Erfolg begründet. Die Antwort ist einfach, die Ausführung kompliziert. Die Idee, deren Umsetzung, die Anlage des Buches, sind die Basis, von der aus die beiden Autoren H.-J. Kretschmann und W. Weinrich mit einem engagierten Team – die Danksagung ist ein Spiegelbild hierfür – ein Projekt in Angriff genommen und realisiert haben, das seinesgleichen sucht. Bestechend und überzeugend für den Anwender, der Gedanke der Funktionalität, dem sich der Neuroanatom H.-J. Kretschmann seit Jahren verpflichtet fühlt und der von dem Neurologen W. Weinrich sinnvoll mitgetragen wird. Von der Tatsache ausgehend, daß „neurofunktionelle Systeme größtenteils in den CT- und MR-Bildern unsichtbar sind", wird eine dreidimensionale Schichtanatomie des Kopfes in höchster Perfektion und mit akribischer Detailtreue vorgelegt, in der jene neurofunktionellen Systeme dargestellt werden. Das Prinzip der topographischen Dreidimensionalität wird zudem seitenmäßig farblich unterschiedlich für die einzelnen Schichten frontal, sagittal, kanthomeatal orientiert und für den Hirnstamm weitergeführt, so daß eine rasche Orientierung, die der Übersichtlichkeit dient, gewährleistet ist. Zu nennen sind in diesem Zusammenhang auch die unterschiedlichen Grauwertstufen bei den gezeichneten anatomischen Strukturen, wie sie bei den CT- und MR-Bildern vorgefunden werden. Alle Faktoren verdichten und erhöhen die Aussagefähigkeit der Bilder. Ebenso der Text, der präzise mit knapper Wortwahl, dennoch ein Höchstmaß an Informationen vermittelt. Die Beschreibung und topographische Zuordnung der neurofunktionellen Systeme, gleichsam die hohe Schule in der Beziehung von Struktur und Funktion, wird ebenso meisterhaft abgehandelt, wie das neuhinzugekommene Kapitel über die Topik der Neurotransmitter und Neuromodulatoren. Literaturverzeichnis und ein exzellent geführtes Sachregister finden sich am Ende eines Buches, das als Standardwerk seinen festen Platz eingenommen hat, zu einem unerläßlichen Helfer geworden ist, oder, wie es im Vorwort heißt, „ein Werkzeug für die Praxis" sein soll!

K.-J. Neumärker (Berlin)