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Typical Neuronal Activity Patterns of the Relay and Nonspecific Thalamic Nuclei in Patients with Spasmodic Torticollis

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Abstract—Unit activity of 50 neurons of the nonspecific (Rt and MD) and relay (Voi and Voa) thalamic nuclei was recorded extracellularly during 14 stereotactic surgeries in spasmodic torticollis patients by a microelectrode technique. An analysis with Poincare maps and gap statistics revealed three main neuronal activity patterns: irregular single spikes, low-threshold Ca^{2+}-dependent rhythmic (3–5 Hz) bursts, and combinations of bursts and single spikes. Grouping (in the Voi and Rt nuclei) and long-burst (in the Voa nucleus) patterns were observed in a few cases. The grouping pattern consisted of low-density groups of spikes with random lengths and a tendency to periodicity in the range from 1 to 1.5 Hz. The long-burst pattern consisted of long dense groups of spikes with random lengths and invariant interburst intervals. Main numerical parameters of the three most common neuronal activity patterns were estimated by a parametric analysis. The thalamic nuclei substantially differed in burst activity characteristics, while their average firing rates did not differ significantly. The results may be used for functional identification of the thalamic nuclei during stereotactic neurosurgery in patients with movement disorders.

Keywords: human, neuron, thalamus, microelectrode, burst activity, oscillation, spasmodic torticollis
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INTRODUCTION

The thalamus is a key structure of the nervous system that is involved in processing sensory signals, producing behavioral responses, and organizing movements and other important functions of the brain in humans and animals. This multiplicity of functions is due to numerous efferent and afferent connections thalamic nuclei have with various cortical areas, subcortical structures, the spine, the brainstem reticular formation, and other structures [1].

Electrophysiological studies of individual thalamic nuclei have revealed diverse firing activity patterns, but there is still no unified classification of thalamic cells by electrical activity pattern [2–9]. Two main neuronal activity patterns, tonic spiking and low-threshold Ca^{2+}-dependent bursting, have been identified in studies with animals [2, 3, 10]. Rhythmical burst activity observed in the studies has been associated with deep sleep or anesthesia. Yet bursting activity in the wake state has been observed in certain thalamic nuclei of monkeys, often arising in response to visual stimuli [11–13]. The finding makes it possible to think that bursting activity of neurons may serve as a means to transmit information.

Attempts to identify the typical patterns for human thalamic neurons have been made with firing activity recorded during stereotactic neurosurgery in patients with various disorders (parkinsonism, dystonia, chronic pain, mental disorders, etc.). For instance, the following patterns have been isolated in neuronal activity of several thalamic regions (the central lateral nucleus, parafascicular complex, and posterior nuclear group): rhythmic and arrhythmic bursting activity forms, irregular spiking, and irregular spiking that responds to somatosensory stimuli or voluntary movements [4, 14]. Comparisons have not revealed significant differences in the prevalence of corresponding neurons for different diagnoses, but bursting activity has still been associated with the pathological condition of the patients. Two bursting activity patterns, short dense bursts and long trains of spikes, have been observed in a study of neuronal activity of the central lateral, central medial, and parafascicular nuclei of the thalamus [5].

Several typical patterns differing in interspike intervals within bursts have been isolated in a study of firing activity for the ventral nuclear group of the thalamus in patients with parkinsonism [15]. A pattern wherein bursting correlates in frequency with tremor has also been observed in parkinsonian patients [15, 16].

To summarize, three main neuronal activity patterns—irregular spiking, Ca^{2+}-dependent bursting, and a combination of spikes and bursts—are characteristic of thalamic nuclei according to published data. The proportion of the patterns differs among the ventral (Vc, Vo, and Vim) thalamic nuclei and influences certain neuronal activity parameters [7, 17].

We have previously described the specifics of background firing activity of neurons of the nonspecific [8, 9, 18] and relay [19, 20] thalamic nuclei in patients with parkinsonism and spasmodic torticollis. This study continues our analysis of the neuronal organization and classification of firing activity of neurons in the relay (Voi and Voa) and nonspecific (Rt and MD) thalamic nuclei.

METHODS

Experimental data were obtained during stereotactic neurosurgery in patients with spasmodic torticollis at the Burdenko Institute of Neurosurgery (Russian Academy of Medical Sciences, the surgeons M.R. Medzhidov and V.A. Shabalov), using a microelectrode technique. Firing activity of neurons was recorded extracellularly with tungsten microelectrodes (active tip diameter 1 μm, resistance 1–5 MΩ). After amplification and instrumental filtering, the signal was digitalized using a L-Card 1250 analog-to-digital converter (neurogram sampling rate 20 kHz) [21].

A microelectrode study was performed during neurosurgery to functionally identify the subcortical structures located along the microelectrode track. Microelectrode tracks from the premotor cortex to surgery targets (the nucleus of Cajal and/or the Voi nucleus) were checked by X-rays or computed tomography against the Atlas of the Human Brain [22]. The patients gave a written consent to surgery. The study was approved by the Ethics Committee at the Burdenko Institute of Neurosurgery.

A preliminary data processing included signal filtration from noise pickup and artifacts and discrimination of neuronal activity by shape and amplitude. In a further analysis, typical neuronal activity patterns were isolated and their quantitative parameters determined.

To classify neuronal activity into characteristic patterns, we constructed a Poincare map (PM) of the interspike interval distribution [17]. A PM is a set of points whose abscissa corresponds to the decimal logarithm from current interspike interval *n* and the ordinate, to the decimal logarithm from next interspike interval (*n* + 1) (Fig. 1c). A neuron was assigned to a particular pattern by evaluating the cluster number in a PM. When single spike activity predominates, one large central cluster is shown in the PM. Two or more clusters suggest grouping activity patterns. Four clusters located in the corners of the PM suggest bursting activity.

Gap statistics was used to evaluate the optimal cluster number in the PM (Fig. 1d) [23].

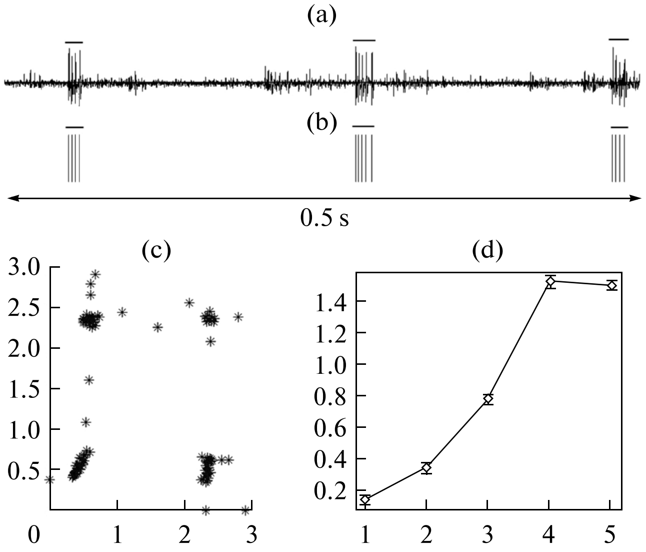


Fig. 1. Classification of neuron firing activity patterns. (a) A neurogram fragment. A burst is shown with a horizontal line over a group of spikes. (b) A train of spikes in neuronal activity. (c) A logarithmic-scale Poincare map. Abscissa, current interspike interval *n*; ordinate, interspike interval (*n* + 1). (d) The gap value as a function of the cluster number. Abscissa, number of clusters; ordinate, gap.

A gap-statistics analysis is based on calculating the sum of squares of within-cluster distances:

$$D_r = \sum_{i \in C_r} \sum_{j \in C_r} \|x_i - x_j\|^2$$

$$= 2n_r \sum_{i \in C_r} \|x_i - \bar{x}\|^2,$$

where x_i and x_j are the elements of the cluster, n_r is the number of elements in the *r*th cluster, and C_r is the set of indices of the *r*th cluster.

The resulting sum of distances can be used to obtain a measure of the compactness of the cluster:

$$W_k = \sum_{r=1}^{k} \frac{1}{2n_r} D_r,$$

where *k* is the number of clusters.

The gap is estimated as the difference between the mean logarithmic expected compactness and logarithmic observed compactness of the cluster:

$$Gap(k) = \frac{1}{B} \sum_{b=1}^{B} \log W_{kb} - \log W_k,$$

where W_{kb} is the expected compactness of a cluster obtained by random sampling from a uniform distribution, W_k is the observed compactness of the cluster, and B is the number of samples from the uniform distribution.

The optimal number of clusters is defined as a minimal *k* that satisfies the condition

$$Gap(k) \geq Gap(k+1) - s_{k+1},$$

where S_{k+1} is the simulation error.

The simulation error is determined for the clusters obtained by sampling from the uniform distribution:

$$s_k = \sqrt{1 + 1/B} \times sd(k),$$

where $sd(k)$ is the standard deviation.

Bursts were identified within a train of spikes by a template method with the following parameters: the minimal number of spikes in a burst is 2, the interspike interval before the first action potential of a burst is no less than 30 ms in duration, and the first intraburst interval is no more than 6 ms. A subsequent spike were considered belonging to the burst if its interspike interval differed by no more than 3 ms from the previous one. The maximal interspike interval within a burst is 16 ms [24].

To quantitatively characterize the isolated activity patterns, we calculated the following parameters: firing rate (FR), burst rate (BR), primary event rate (PR), BR to PR ratio (BR/PR), burst-related spike percent (BP), mean preburst interspike interval (PBISI), mean pre-primary event interspike interval (PRISI), PBISI to PRISI ratio (PBISI/PRISI), mean interburst interval, mean intraburst rate, mean burst length (BL), mean spike number in a burst (SB), and mean first and mean last intervals in a burst [17].

A quantitative analysis of firing activity was performed for a total of 50 neurons of the nonspecific (15 Rt and 9 MD neurons) and relay (15 Voi and 11 Voa neurons) nuclei of the human thalamus, using the data recorded during 14 stereotactic neurosurgeries in patients with spasmodic torticollis.

RESULTS

Neuronal activity of the relay (Voi and Voa) and nonspecific (Rt and MD) thalamic nuclei was classified into several typical patterns, including single pattern (40%), burst pattern (26%), mixed pattern (24%), a grouping pattern (8%), and long burst pattern (2%).

The single-spike pattern was seen as one diffuse cluster in a PM and was characterized by single irregular spikes occurring at a rate of 1.9–36.8 spikes/s (median 7.7 spikes/s) with rare bursts. An unimodal interspike interval histogram (ISIH) with a Poisson-like distribution and a lack of distinct modes in an autocorrelation histogram (ACH) and spectrum showed that this firing activity was irregular (Fig. 2).

The burst pattern, which corresponded to four compact clusters, consisted in neuronal activity with short dense groups of discharges with silent intervals (of at least 30 ms) between them. A bimodal ISIH with modes at 2–4 ms and 0.2–0.3 s and the presence of distinct modes in the autocorrelation histogram (bin - 10 ms) suggested a regular character for this activity pattern. A spectral analysis revealed a rhythmic mode in the range 4–5 Hz. A unimodal distribution of the autocorrelation histogram (bin = 0.5 ms) showed that discharges were irregular within a burst (Fig. 2). An analysis of the internal burst structure showed a deceleration from the first ISI of 3.3 (3.0–3.5) ms to the last ISI of 4.2 (3.7–4.3) ms.

The mixed pattern corresponded to 3–5 clusters and included trains of single spikes alternating with bursts. Mixed firing activity slightly tended to periodicity, which was mostly due to the characteristics of rhythmic burst discharges (Fig. 2). This was evident from indistinct modes in the ISIH and ACH. A spectral analysis revealed rhythmic activity of 3–4 Hz. In contrast to the burst pattern, the mixed pattern was unstable. The internal structure of bursts similarly showed a deceleration pattern.

The grouping pattern included firing activity in the form of low-density (100–200 spikes/s) groups of discharges with a duration of 20–30 ms. The intergroup interval varied from 0.1 to 1 s. A unimodal Poisson-like distribution of the ISIH showed that firing was irregular in this pattern. In contrast to single-spike and burst patterns, the grouping pattern tended to regular firing activity within groups, as was evident from the polymodal distribution of the ACH (bin = 0.5 ms). The autocorrelation histogram and spectrum suggested a weak periodicity in the range 1–1.5 Hz (Fig. 3).

The long-burst pattern was characterized by long (from 100 ms to 1 s) dense (ISI = 2.8 ms) groups of discharges with an invariant (100–120 ms) intergroup interval (Fig. 3). This was evident from the bimodal distribution of the ISIH (bin = 10 ms) and the presence of periodical modes in the ACH (bin = 10 ms). Another feature of this activity pattern was that discharges were regular within bursts, as evident from the Gaussian distribution of the ISIH (bin = 0.5 ms) and the presence of several modes in the ACH (bin = 0.5 ms). A spectral analysis did not reveal any predominant frequency component (Fig. 3).

A parametric analysis was performed for the three most common patterns and yielded numerical estimates for the main parameters of neuronal activity (table).

As is seen from the table, the single-spike and burst patterns were similar in firing rate (FR; 7.7 and 7.6 spikes/s, respectively), while the mixed pattern had a lower firing rate (5.8 spikes/s). The FR distribution of the burst pattern showed the lowest deviation from the normal distribution, indicating that the frequency characteristics of the burst pattern were the most stable.

The percentage of burst-related spikes (BP) varied from 9.6% in single-spike activity to 77% in the burst pattern. The mixed pattern had an intermediate BP (45%); i.e., the portions of single spikes and bursts were almost equal in this pattern.

The BR/PR ratio, which characterizes the frequency of inhibitory influences, differed among the

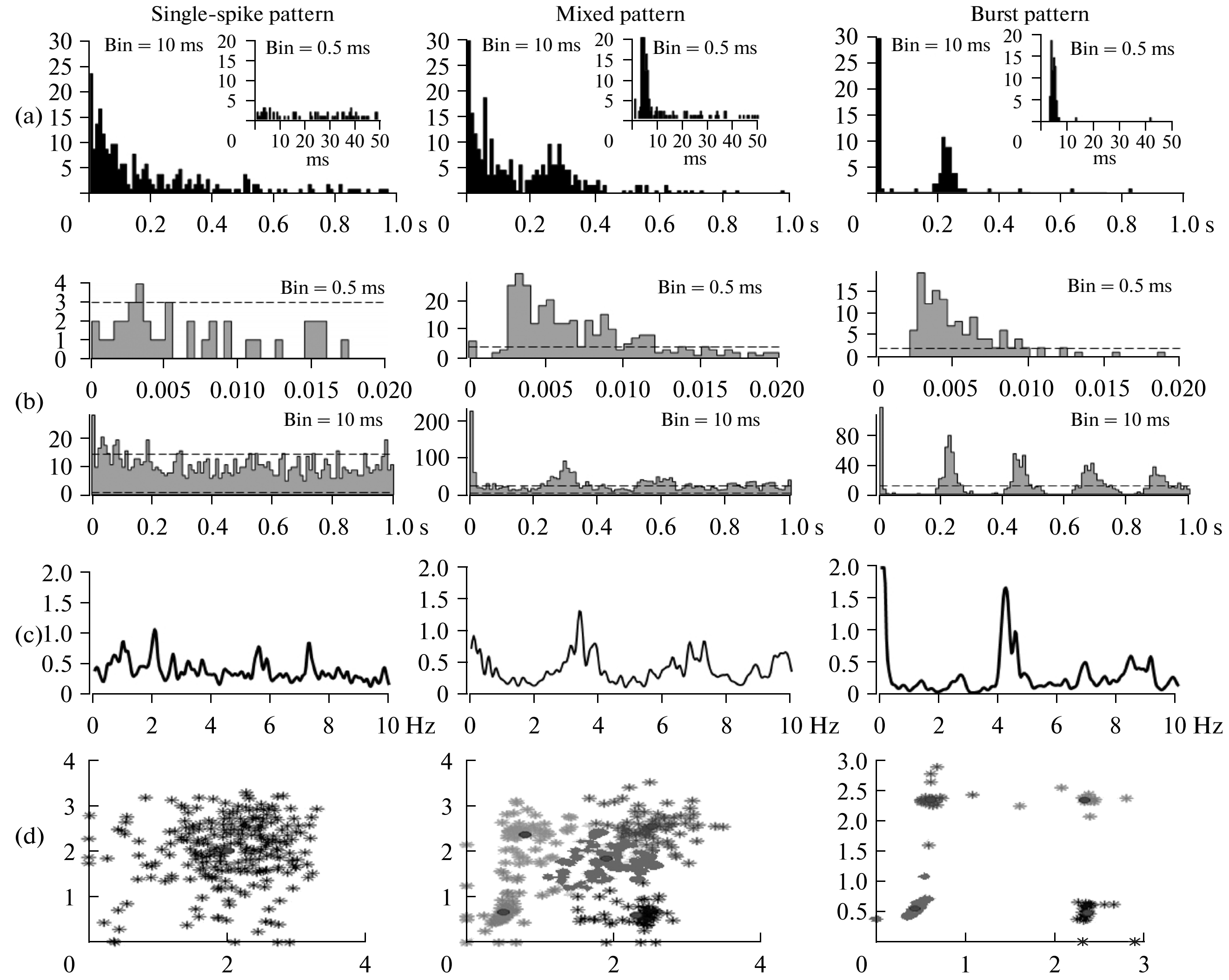


Fig. 2. Firing activity patterns including single spikes, a combination of single spikes and bursts, and bursts. (a) Interspike interval histograms. Abscissa, interspike interval duration (s); ordinate, number of interspike intervals per bin. (b) Autocorrelation histograms. Abscissa, time (s); ordinate, number of interspike intervals per bin. (c) Spectra. Abscissa, frequency (Hz); ordinate, spectral power (%). (d) Logarithmic-scale Poincare maps. Abscissa, current interspike interval *n*; ordinate, interspike interval (*n* + 1).

patterns in question. Its lowest value (0.04) was observed for the single-spike activity pattern; the highest value (0.34), for the burst pattern; and an intermediate value (0.18), for the mixed pattern. The parameter indicates that the highest frequency of inhibitory influences is characteristic of the burst pattern.

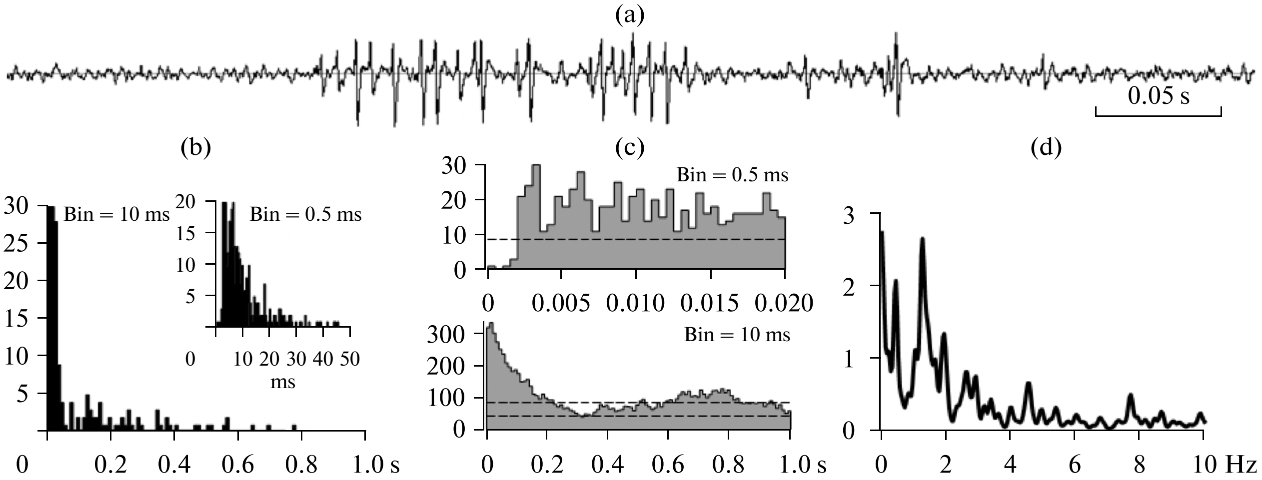
PBISI tended to increase slightly from single spikes (0.21) to the burst pattern (0.33). PRISI did not depend on the burst-related spike percent, but correlated indirectly with firing rate. The PBISI/PRISI ratio, which characterizes the intensity of inhibitory influences, was maximal (1.92) in the burst pattern and minimal (1.37) in the mixed pattern.

For the burst and mixed patterns, we additionally estimated the intra- and interburst intervals, mean burst length, mean firing rate in a burst, mean number of discharges per burst, and mean first and mean last intraburst intervals.

Burst activity consisted predominantly of bursts (BP 58.8–95.8%), the mean number of spikes per burst (SB) varied from 3 to 6, and the burst length (BL) ranged from 6.7 to 11.8 ms. Bursts similarly accounted for a substantial portion of mixed activity (BP 11.1–53.1%); SB varied from 2 to 4; and BL varied from 5.8 to 8.8 ms. Single-spike activity consisted predominantly of single discharges with a minor portion of burst-related spikes (BP 0–27.4%).

The internal structure of bursts was described by the mean first and mean last interspike intervals in a burst, mean intraburst interval, and mean intraburst rate. The parameters did not significantly differ among the three most common patterns. The internal structure of bursts displayed a deceleration pattern, which

Grouping pattern



Long-burst pattern

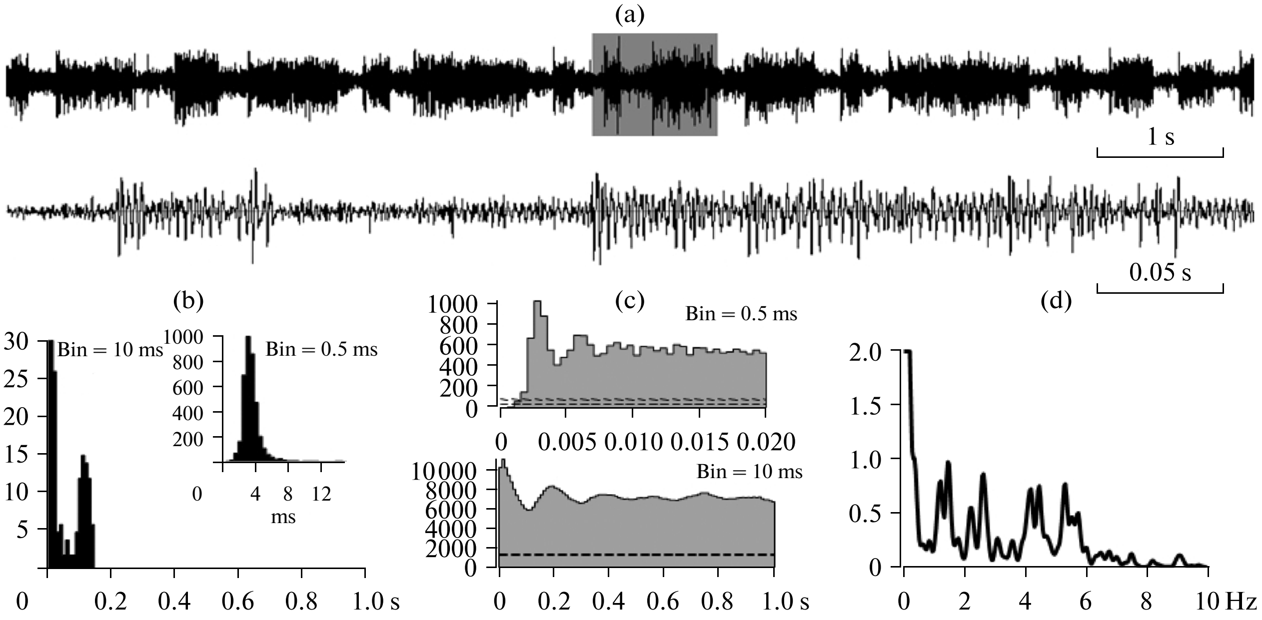


Fig. 3. Grouping and long-burst patterns of firing activity. (a) A neurogram fragment. (b) Interspike interval histogram. Abscissa, interspike interval (s); ordinate, number of interspike intervals per bin. (c) Autocorrelation histogram. Abscissa, time (s); ordinate, number of interspike intervals per bin. (d) Spectrum. Abscissa, frequency (Hz); ordinate, spectral power (%).

suggests a Ca^{2+}-dependent nature for the neurons according to the literature [10, 14, 25].

A distribution of the activity patterns among the thalamic nuclei is shown in Fig. 4. Single-spike activity was observed in all of the nuclei examined, especially in Voi (67%) and Rt (34%). Mixed activity was similarly found in all of the nuclei and was the most prevalent in Rt (53%). The burst pattern was detected in all but one (Rt) nucleus, being the most prevalent in the Voa (60%) and MD (67%) nuclei. The long-burst pattern was restricted to the Voa nucleus (10%), and the grouping pattern was observed in the Voi (13%) and Rt (13%) nuclei.

Our analysis showed that some of the neuronal activity parameters significantly differed between the thalamic nuclei (Fig. 5). The highest burst-related spike percent was observed for the MD (76.6%) and Voa (60.8%) nuclei. In addition, the two nuclei displayed the longest bursts with a mean spike number per burst of more than 3. A lower percentage of burst-related spikes was observed for the Rt (31.5%) and Voi (9.5%) nuclei. Similar differences were found for BR/PR, which characterizes the frequency of inhibitory influences. BR/PR was maximal (0.34) in the case of MD neurons and minimal (0.041) in the case of Voi neurons. Neurons of the Rt nucleus displayed an intermediate BR/PR (0.124). It should be noted that

Characteristics of the three main patterns of neuron firing activity in the human thalamus

Parameter	Median	Minimum	Maximum	Lower quartile	Upper quartile
Single-spike pattern					
FR	7.717	1.900	36.813	4.139	13.444
BP	9.610	0.000	27.397	1.730	18.685
BR	0.243	0.000	1.438	0.103	0.563
PR	7.669	1.800	36.063	3.952	13.359
BR/PR	0.042	0.000	0.118	0.009	0.081
PBISI	0.214	0.057	0.592	0.087	0.356
PRISI	0.113	0.027	0.496	0.068	0.217
PBISI/PRISI	1.544	0.697	4.128	1.108	2.639
Mixed pattern					
FR	5.866	1.690	30.438	2.259	9.735
BP	45.614	11.111	53.061	38.224	47.561
BR	0.714	0.269	3.333	0.364	1.353
PR	4.866	1.385	26.313	1.920	8.147
BR/PR	0.175	0.051	0.250	0.137	0.194
PBISI	0.273	0.107	0.940	0.196	0.419
PRISI	0.200	0.039	0.702	0.124	0.507
PBISI/PRISI	1.370	0.768	3.054	0.978	2.208
Burst pattern					
FR	7.609	3.548	12.171	5.929	9.375
BP	77.333	58.784	95.814	64.591	82.331
BR	1.419	0.824	2.550	1.269	2.125
PR	5.478	2.645	6.286	3.735	5.742
BR/PR	0.340	0.241	0.464	0.268	0.360
PBISI	0.329	0.244	0.743	0.310	0.394
PRISI	0.169	0.119	0.349	0.155	0.258
PBISI/PRISI	1.915	1.242	2.832	1.622	2.181

the BR/PR ratio was highly variable in the case of the Voa nucleus (0.244, 0.003–0.354).

In contrast to BR/PR, the PBISI/PRISI ratio differed to a lower extent. The highest intensity of inhibitory influences by PBISI/PRISI was observed for the MD (2.181) and Voa (1.915) nuclei. The Voi nucleus also experienced intense inhibitory influences (1.6) in spite of the predominance of single-spike activity. The lowest inhibitory influences were observed for the Rt nucleus (1.37).

It is important to note that the nuclei showed only minor differences in firing rate. The Rt nucleus was an exception, having a somewhat lower FR, which was due to a predominance of neurons with mixed activity in the nucleus.

In total, the parametric analysis revealed significant differences in background firing activity between the nonspecific (MD and Rt) and relay Voi nuclei of the thalamus. The Voa nucleus, which belongs to relay nuclei, displayed firing activity parameters of both nonspecific (Rt and MD) and relay (Voi) nuclei.

DISCUSSION

In this work, we classified neuronal activity of the nonspecific (Rt and MD) and relay (Voi and Voa) nuclei of the human thalamus with the use of Poincare maps and gap statistics. Three main patterns were observed for neuronal activity: single spikes, bursts, and a combination of both.

Neuronal activity characteristic of the three most common patterns identified in our study has been observed in other studies, both in experiments with animals and during surgery in dyskinesia patients [4, 5, 7, 11, 14, 15, 17, 26]. However, there is still no consensus of opinion as to whether the firing activity patterns are specific for particular thalamic nuclei and what functional role the patterns play.

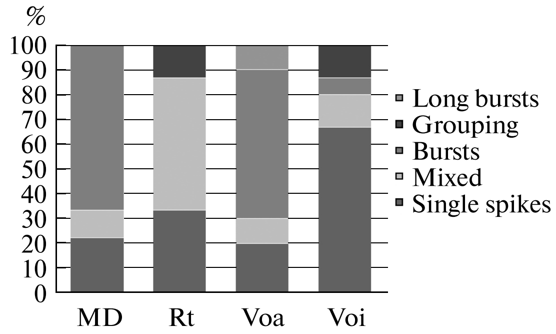


Fig. 4. Distribution of the neuronal activity patterns in the relay (Voi and Voa) and nonspecific (Rt and MD) nuclei of the thalamus. Ordinate, the percentage of neurons with the corresponding pattern (shown by shade intensity).

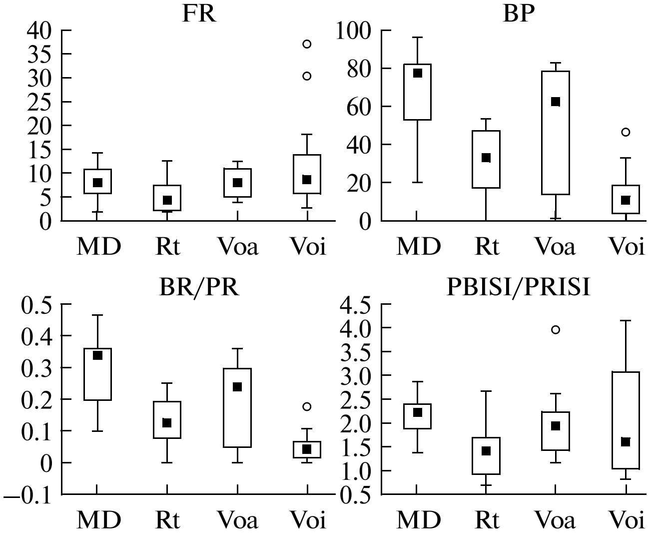


Fig. 5. Neuronal activity parameters of the relay (Voi and Voa) and nonspecific (Rt and MD) thalamic nuclei. FR, firing rate; BP, burst-related spike percent; BR/PR, bursting rate to primary event rate ratio; PBISI/PRISI, mean preburst interspike interval to mean pre-primary event interspike interval ratio. The median is shown with a filled square. The upper and lower sides of a bar correspond to the 75 and 25% quartiles, respectively. Whiskers show the minimal and maximal values within the 1.5 interquartile range from the bar side. Open circles show the values falling outside the range.

Basic mechanisms generating irregular single-spike activity and low-threshold Ca^{2+}-dependent activity have been studied and described in experiments with animals [2, 3, 10]. The functional role of low-threshold Ca^{2+}-dependent bursts is still a matter of discussion. It is thought that similar activity forms are associated with deep sleep in animals [2, 3] or a pathological condition in humans [2–5, 15]. An analysis of burst activity in patients with pain syndrome and other disorders have made it possible to assume that burst activity plays a role in the human brain function during waking as well [27].

We have previously described two main types of neurons, with irregular single-spike activity and low-threshold Ca^{2+}-dependent burst activity, for the reticular (Rt) and ventrolateral (VL) thalamic nuclei of patients with parkinsonism [19, 20] and the parafascicular (CM-Pf) complex in patients with spasmodic torticollis [9]. The functional roles of the two neuron types have been identified as transmission of meaningful signals for neurons with single-spike activity and modulation of insignificant information for neurons with burst activity [9, 18, 28]. Neurons with rhythmic burst activity have been implicated in transmitting significant information during activation of selective attention and voluntary movements in humans [18, 29, 30].

In this work, a mixed pattern of neuronal activity was identified along with the known patterns in the quantitative analysis of the firing parameters of neurons from the nonspecific (MD and Rt) and relay (Voi and Voa) thalamic nuclei of spasmodic torticollis patients. The functional role of the mixed pattern remains unclear. We think that the mixed pattern results from multiple transitions between single-spike and burst activities. This may take place when the transmembrane potential is affected by exciting and inhibitory influences alternating frequently or is continuously exposed to weak inhibitory influences.

The former case suggests an interaction between several brain systems. As is well known, the relay thalamic nuclei in question receive afferent projections from the cerebral cortex, pallidum, and, partly, cerebellum [1]. Mixed activity of the relay nuclei may thereby result from competitive interactions of pallidum, cerebellar, and cortical feedbacks. If so, the pattern can be considered to be a border state of the neuron between different functional modes. For example, Park et al. [31] consider thalamic nuclei to be integrators of signals of different cerebral motor systems; thus, the mixed activity pattern may be an integrated motor signal.

In the latter case, the majority of single discharges are actually "degenerate" bursts, which are sets of single spikes arising rhythmically at a frequency of 3–5 Hz. The mechanism of origin of degenerate burst is similar to that of low-threshold Ca^{2+}-dependent bursts upon long-term exposure to a weak depolarizing effect resulting in only one Na/K discharge [17].

Little information is available in the literature for neuronal activity of the long-burst [32] and grouping [33] patterns identified in our study. The features of the grouping pattern included a lack of distinct internal structure with a weak tendency to regularity and a distinct rhythmic character (1–1.5 Hz). These frequency characteristics differ from the frequency characteristics of well-known Ca^{2+}-dependent burst activity (3–5 Hz), suggesting different mechanisms of origin for bursts and groups at the cell level. While periodic involuntary head movements of the same frequency range are observed in spasmodic torticollis patients, the grouping pattern can be assumed to reflect the pathological condition.

The long-burst pattern was characterized by a regular internal structure, a high firing rate (up to 500 spikes/s), a high variation of the burst length, and an invariant interburst interval (100–120 ms). Similar neuronal activity has been observed in the Rt thalamic nucleus of parkinsonian patients [8, 16] and the parafascicular complex (CM-Pf) in spasmodic torticollis patients [9, 18] in our previous studies. The mechanism generating this activity is unknown. A constant interburst interval disagrees with the mechanism generating high-frequency single-spike activity, while a regular structure, a large number of discharges in a burst, and a high variation of burst length disagree with the mechanism generating Ca^{2+}-depending forms of burst activity. Taken together, these data suggest a specific mechanism of origin.

The proportions of the neuronal activity patterns in the different functional groups (nonspecific and relay) of thalamic nuclei did not reveal the activity types that would be specific for a functional group. This is probably related to the fact that the three most common neuronal activity patterns are general thalamic patterns according to the classification used.

The quantitative distribution of the three most common neuronal activity patterns in the nuclei in question showed several features. For instance, a similarity in pattern distribution between the MD and Voa nuclei is possibly indicative of their functional relationship. In fact [1, 19], the Voa nucleus is associated not only with a direct execution of motor acts, but also with the cognitive aspects of movements, such as planning and initiation of voluntary movements. A predominance of the mixed activity pattern in the Rt nucleus is possibly related to the intricate structure of its connections. The Rt nucleus is connected with the cortex and the majority of the thalamic nuclei both directly and via an intrathalamic interneuron network [34]. In view of this fact, interplay of exciting and inhibitory influences takes place in the nucleus to generate continuous changes in transmembrane potential and, therefore, a mixed pattern of neuronal activity.

It should be noted that the burst pattern, which is often associated with a pathological condition, had the highest prevalence in the MD and Voa nuclei, while its prevalence was far lower in the Voi nucleus, which was a surgery target. The fact suggests a lack of direct correlation between burst activity and the pathological condition of spasmodic torticollis. The mixed pattern with a low burst portion was the most prevalent in the Rt nucleus. This finding provides again indirect evidence for the idea that burst activity forms observed in the Rt nucleus are in intricate indirect correlation with the tremor symptom in parkinsonian patients, as we have described previously [8].

CONCLUSIONS

To summarize, our study revealed several neuronal activity patterns in the thalamic nuclei: irregular single spikes, rhythmic bursts (3–5 Hz), and their combination. Numerical estimates were obtained for the parameters of the patterns and showed that their mechanisms of origin are similar in different human thalamic nuclei. We showed that the human thalamic nuclei under study significantly differ in burst activity characteristics, while their mean firing rates were much the same. The findings contribute to the understanding of the burst character of discharges and, on the other hand, are of applied significance for a functional identification of thalamic nuclear structures during stereotactic neurosurgery in patients with motor disorders.

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