zinc deficiency. Zinc deficiency also causes a decrease in the activities of lactic dehydrogenase, alcohol dehydrogenase, alkaline phosphatase and some other enzymes[12]. In addition to these alterations, the present results clearly indicate that lung ACE also decreases in the zinc-deficient rats. Changing the zinc-deficient to the normal diet has been shown to cause a recovery in the decreased activity of the enzymes investigated[12,13]. Whether or not the same recovery also occurs in the activity of ACE is under investigation.

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A simple interspike interval analyzer for study of neuronal spike trains

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Summary. A simple, low cost interspike interval analyzer for the analysis of trains of nerve impulses is described. The analyzer is built with readily available integrated circuits and has been used to analyze spike trains in the lateral vestibular nucleus of cats.

Analysis of trains of nerve impulses of spikes is a common approach in the study of information transmission in the nervous system. That stimulus intensity is coded in terms of spike discharge frequency was first discovered by Adrian and Zotterman[2]. Since then the concept of a rate or frequency code in neuronal activities has been widely accepted. In 1946, the possible significance of the interspike interval in neural coding was first pointed out by Brink, Bronk and Larrabee[3]. Although a number of possible codes involving statistical analysis in the time and frequency domains have since been proposed[4,5], the interspike interval histogram has remained an important tool in attempts to decipher the code in impulse trains. We have designed and built a simple interval analyzer with LED dipslays which could also be linked to a X-Y plotter for instant plotting of data. The interval analyzer is easy to construct and consists of low cost integrated circuit components. The block diagram for the interspike interval analyzer is shown in figure 1. The essential components are a series of counters (SN 7490), random access memory chips (MM 2102), magnitude comparators (SN 7485) and a crystal oscillator.

The analyzer is governed by a sampling time control which determines the time during which analysis of the intervals is to be made. Preselected sampling time ranging from 10 to 90 sec or longer is derived by dividing a 1-kHz signal from an oscillator through a series of decade counters. Output from the sampling time control circuit is used to gate the input signals, i.e. nerve impulses, into a pulse counter. The pulse counter then totals the number of spikes that have appeared within the preselected sampling time. This number is instantaneously displayed. The nerve impulses are also fed in parallel to an interval counter, which is also driven by the 1-kHz oscillator and is capable of measuring intervals with an accuracy of ± 1 msec. The interval counter consists of a series of one-shot monostables triggered by each incoming signal. These monostables serve a dual function. They enable the memory units for storage of

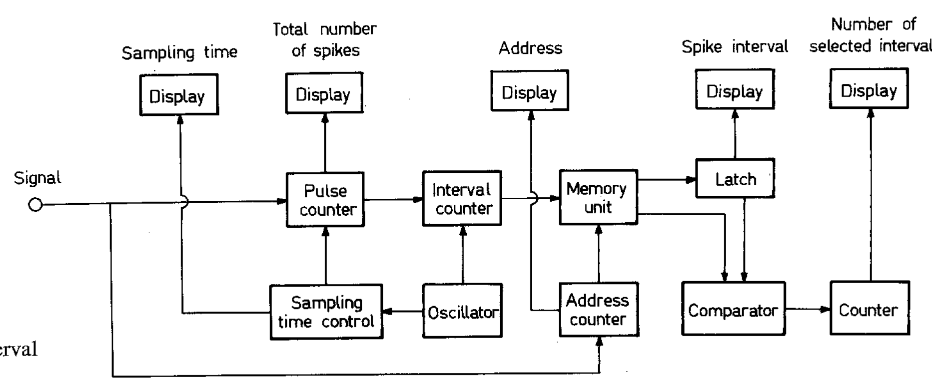

Fig. 1. Block diagram for the spike interval analyzer.

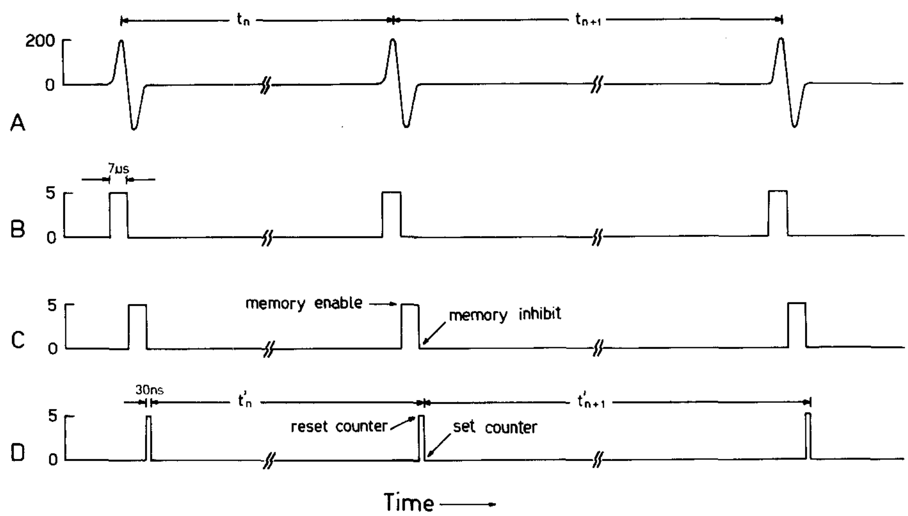

Fig. 2. Interval counter. Each nerve impulse (A) triggers a one-shot monostable to give a 7-µsec pulse (B) which in turn gates the counting of another 7-µsec pulse (C). The high and low level states of this latter pulse are used to enable and inhibit the memory chips, respectively. A 30-nsec narrow pulse (D) is also triggered by the falling edge of the 7-µsec pulse in (C). The leading edge of the narrow pulse is used to reset the interval counter at the completion of memory operation after reading t'_n and its falling edge starts the counting of the next interval t'_{n+1}. The difference of 14 µsec between t_n and t'_n is negligible.

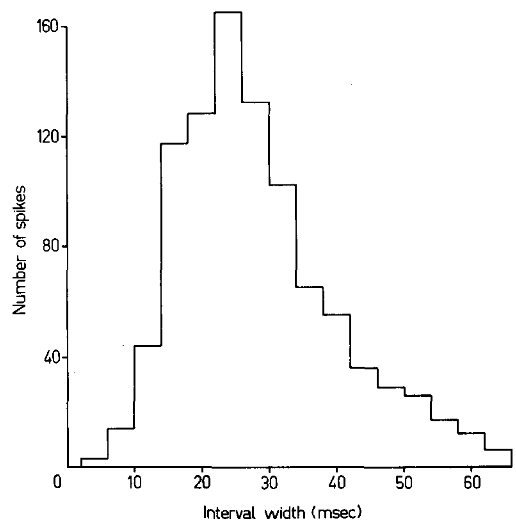

Fig. 3. Interspike interval histogram. Data obtained from lateral vestibular nucleus of cat in a horizontal position.

successive interval values, and they also clear and set the counter to read to value of the next interval (figure 2).

The memory unit consits of 12 random access memory (RAM) chips each with 1024 bits. This is necessary because the output display for the intervals required a range of 3 digits in msec. Since each digit is composed of 4 bits, a memory capacity of 1024 digits is required. The RAM chips are used to store the successive interspike intervals occurring within the period of the sampling time. The data stored in the memory units can be retrieved one by one and are temporarily stored in the latch unit. The output of the latch unit goes to input A of the comparator unit, while input B is connected directly to the output of the memory units. The latch unit consists of 3 bistable latches (SN 7475). This unit is used for temporary storage of information coming from the memory unit. Any preselected interval stored in the memory unit can be latched on and compared sequentially with all the other interspike intervals stored in the memory unit. The preselected interval is decoded (SN 7447A) and displayed as well. The comparator will only allow intervals of a magnitude equal to that temporarily stored in the latch unit to pass through. Output from the comparator is then totalled in a counter and displayed as the frequency of occurrence of a particular interval.

An address counter is also used to assign an address to each information stored in the memory unit. The address counter itself is triggered sequentially by each incoming nerve impulse. The assignment of address is necessary for data retrieval from the memory units to enable latching of any preselected interval and subsequent comparison with other intervals stored in the memory unit. The stored intervals that compare with the preselected latched value are reset to 0 at the end of each comparison so as to prevent reappearance with consequent redundance in later comparison operation. The address counter is advanced either manually or by a timer in a sequentially manner, such that the intervals stored in the memory units are automatically, and consecutively transferred to the comparator in the order of the address number.

The interval analyzer so constructed is used to analyze spike trains recorded from the lateral vestibular nucleus (Deiters' nucleus) in cats. Cats anaesthetized with ketamine hydrochloride[6] (Ketalar, Parke Davis), were mounted in a modified stereotaxic frame (David Kopf Inst., model 1404). Activity of single vestibular neurons was recorded extracellularly with tungsten microelectrodes with tip impedance of 5–15 MΩ. The recording microelectrodes were inserted dorsoventrally through the exposed cerebellum at an angle of 40° posterior to the vertical plane. Accurate placement of the recording microelectrode was verified by characteristic field potentials in response to direct electrical stimulation of the exposed saccule[7]. Action potentials recorded by the microelectrodes were amplified (Grass AC/DC Amplifier, model P16) before being fed into the interval analyzer. The animal was then either pitched or rolled. Figure 3 depicts an interspike interval histogram using the interval analyzer for data recorded from the Deiters' nucleus with the animal in the horizontal position.

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