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Frequency dependence in acupuncture manipulations

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Abstract- **The internal frequencies of chain network of FHN neurons include two different frequencies, namely, the intrinsic and Canard frequency. When the frequency of external stimuli approaches to the values of these two frequencies, signal processing in the chain will be enhanced. In traditional medical of Chinese acupuncture, signals evoked by different manipulations follow certain tracts to reach different target tissues. So it is reasonable to establish a chain network of FHN neurons to mimic the tract for frequency study.**

Keywords–intrinsic frequency, Canard frequency, chain network of FHN neurons, acupuncture, manipulation

I. INTRODUCTION

The response of an excitable system to external stimuli is a key effect of information processing in a single excitable oscillator or networks of excitable elements [1]. The improvement of a signal processing occurs due to the resonance interplay between an external periodic stimuli and one of the internal frequencies of the oscillating system [2]. As reported in this work, the chain network of FHN neurons built here occupies two different internal frequencies, namely intrinsic frequency and Canard frequency. The former one is of lower value while the latter one owns a higher value. That is the reason why some researches [1] take two periodic stimuli, namely two inputs at low and high frequency, into the neuron system to investigate the vibrational resonance. And in the background of noise, external stimuli at Canard frequency can improve signal transmitting in the nervous system, reported by [1], is named as "Canard enhanced SR" which is crucial that not the amplitude but the frequency of the high frequency signal should be in resonance with the oscillatory behavior of a system. Canard takes place in FHN-like models or in biophysical models when their parameters are chosen in the region of the Canard bifurcation [3]. And when the bifurcation point in a single FHN model is near the Canard point, the model is tuned to have both oscillatory and excitatory properties. Acupuncture is well known as a key part of traditional Chinese medicine (TCM) theory and it is approved to be highly effective in treatment of more than 300 diseases [4]. Acupuncture at the tsu san li point is not only utilized to treat diseases of common digestive system such as duodenum ulcer, acute gastritis and gastroptosis etc, but also has auxiliary efficiency on enteritis, hypertension, constipation, kidney stone, hepatitis, gallstone, diabetes and dysentery [5]. When acupuncture is applied to the tsu san li point, the corresponding electrical activity can be recorded from the spinal dorsal horn [6]. We use the chain network of FHN neurons to mimic the path from tsu san li point to spinal dorsal horn to study the influence of frequency of the external stimuli in both these two systems as well as to draw a comparison.

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II. EXPERIMENT AND MODEL ABSTRACTING

According to mass of previous contributions whether in clinical treatment or in the theory of TCM, the acupuncture signals produced by different manipulations follow certain routes from the acupuncture points to the target organs. The corresponding transmission path for acupuncture signals from tsu san li point is shown in Fig.1. Here we take twirling manipulations of different frequencies at tsu san li point of laboratorial rat rather than doing such invadable experiments directly in human bodies. Then the electrical signal time series at the spinal dorsal horn can be recorded.

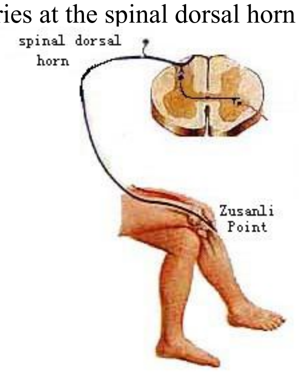

Fig.1 The transmission path of the acupuncture signals from tsu san li point to spinal dorsal horn

In the first step of experiment, the target tissue, spinal dorsal horn, should be got by dissecting the laboratory mouse, and then the twirling manipulations at different frequencies are taken at tsu san li point. Accordingly, the evoked electrical signals at the dorsal nerve root of spinal cord are recorded by multipurpose polygraph. Finally, the recorded data will be sent to the computer to be analyzed. The interface chart of the equipments which is also a flow chart is shown in Fig.2.

The twirling manipulations are manipulated at four different frequencies, namely, 50,100,150 and 200 circles per minute. In every frequency, the same experiment is taken three times. In each time, we twist 20 seconds then stop and keep the needle still with 100 seconds. Whenever we take manipulations to certain acupuncture points, it is impossible to avoid noise, e.g., the pain caused by the needle, the dithering of doctor's hand during the treatment and the internal neuron noise. Therefore, the authors try to mimic the tract by constructing a chain network of FHN neurons in the background of white noise, and study how the frequency of an external sine like periodic stimuli matches the internal frequencies of the network, as well as the effect of external noise.

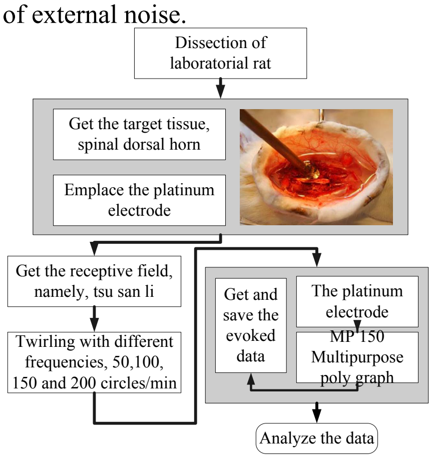

Fig.2 The flow chart of the biotic experiment

We consider a simple model with a simplistic scheme of connections, i.e., a signal injected through a neuron making the signal transmit along the network of several (three or more) FHN oscillators coupled with inhibitory coupling, that can retain the basic structure of the system we want to mimic. This kind of architecture may be reasonable for the transmission path of the acupuncture signals although its form of couple couldn't be ascertained to be inhibitory. However, inhibitory coupling exists widely in the neuron system [7]. Moreover, we want to study whether a periodic, subthreshold signal, acting on one element can reach the others. The network model is presented in Fig. 3.

The scheme in Fig.3 includes FHN oscillators with the number equaling to N, which are coupled through the inhibitory variables:

$$\begin{aligned} &\varepsilon \dot{x}_i = -y_i - x_i^3 + x_i \\ &\dot{y}_i = a_i + x_i + B\xi_i(t) - D(y_{i-1} - y_i) - D(y_{i+1} - y_i) \end{aligned} \tag{1}$$

where the neuron cell membrane voltage x_i and the recovery variable y_i are considered as dimensionless variable, and i denotes the number of FHN neurons. We fix $\varepsilon = 0.01$ throughout this paper which is a time scale variable and $a_i = 1.01$ $(i = 1,2,3)$ is a bifurcation parameters; $\xi_1(t) = \xi_2(t) = ... = \xi_N(t)$, indicating the neuron network being in stimuli of the same noise, are assumed to be Gaussian white noise with zero mean and correlation $\langle \xi(t)\xi(t')\rangle = B^2\delta(t-t')$ in which B represents its intensity. In the single FHN neuron without any noise, for $|a| > 1$ the system has only a stable fixed point corresponding to the quiescent state of the system, while for $|a| < 1$ there exists a globally stable limit cycle. $A = 0.03$, is the amplitude of the sine like periodic stimuli and ω is the angular frequency of it.

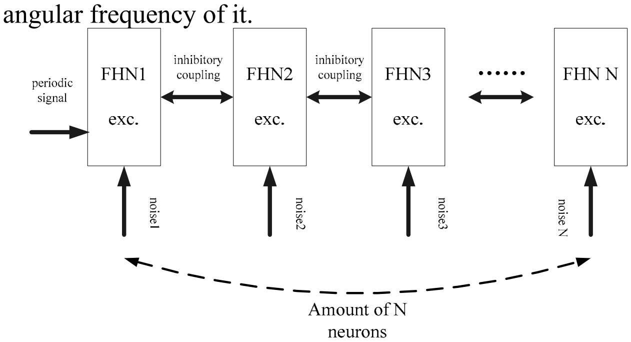

Fig. 3 Scheme of the chain network of FHN neurons: At each end there is excitable unit, coupled through inhibitory coupling each other

To evaluate the response of output frequency to the input frequency, we calculate the Fourier coefficient Q for the input signal. The definition of Q [1] is

$$\begin{aligned} Q_{\sin}^i &= \frac{\omega}{2pn}\int_0^{2pn/\omega} 2x_i(t)\sin(\omega t)dt, \\ Q_{\cos}^i &= \frac{\omega}{2pn}\int_0^{2pn/\omega} 2x_i(t)\cos(\omega t)dt \\ Q^i &= \sqrt{Q_{\sin}^{i\ 2} + Q_{\cos}^{i\ 2}} \end{aligned} \tag{2}$$

where n is the number of periods $2p/\omega$ covered by the integration time. Since our research concentrates on the transport of the information encoded in the frequency of input stimuli, Q parameter is used instead of the power spectrum. In addition, Q parameter is a much more compact tool than the power spectrum [1]. Furthermore, for the Fourier coefficients are exactly proportional to the square of the spectral power amplification which is frequently used as a measure for SR, the signal-to-noise ratio S is computed as the average value of all Q^i, i.e., $S = N^{-1}\sum_{i=1}^{N} Q^i$ [8].

III. THE EFFECT OF FREQUENCY, COUPLING STRENGTH AND NUMBER OF NEURONS IN THE NETWORK ON SNR

According to the established results which suggest that small D essentially forces all units detach from each other, and on the other hand, large D makes the whole array act as a single unit, and the simple and well established reason that larger D better dissipate the influence of the oscillators, while simultaneously the directly perturbed oscillator is more strongly influenced by its neighbors and therefore its response becomes increasingly distorted, we let the coupling strength D to be in the range of 0 to 0.1 here. And by the results of reference [8] and our simulation, D in this range is reasonable for study influence of the frequency of external periodic stimuli and noise. Moreover, it is again in accordance with the observation that only small Ds allow for the occurrence of the locally optimal response, whereas larger Ds increasingly blur the details of the scale-free network structure, making the whole system essentially behave more and more like a single unit. For the locally optimal response, lower Ds are preferred.

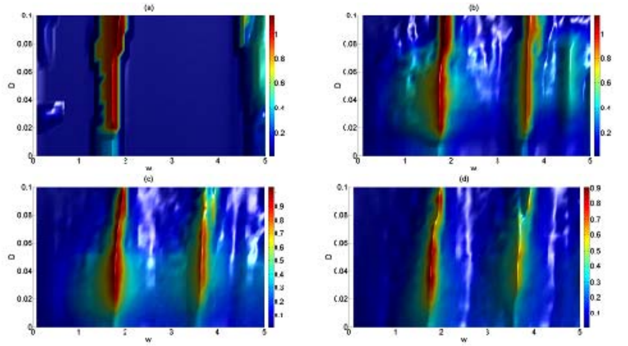

Fig.4 Graph of $\omega - D - S$: (a) $B = 0, N = 3$. (b) $B = 0.002, N = 3$. (c) $B = 0.005, N = 3$. (d) $B = 0.01, N = 3$

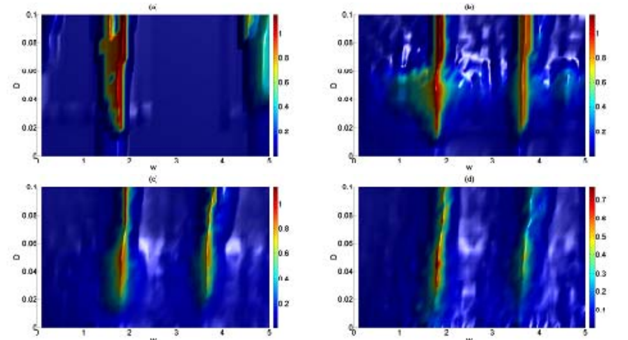

Fig.5 Graph of $\omega - D - S$: (a) $B = 0, N = 10$. (b) $B = 0.002, N = 10$. (c) $B = 0.005, N = 10$. (d) $B = 0.01, N = 10$.

Fig.4 to Fig.9 have displayed the graphs of $\omega - D - S$. Coupling plays here a role similar to that of standard phase transitions, suppressing fluctuations and coupling the stable regions. It prevents the system from visiting the whole available phase space and locks it close to the stable steady state, until a perturbation triggers an excitable spike. The first peak in figures 4 to 9 near $\omega = 1.8\ rad/s$ (the intrinsic frequency) corresponds to a period length of $T_s = 3.49\ s$ and is caused by the firing of spikes. The second peak at about $\omega = 3.6\ rad/s$ is caused by the Canard oscillations near the fix point with a small amplitude compared with the big spikes. It is important to note that a peak at the Canard frequency exists with very small noise intensities while the peak at the intrinsic frequency exists not depending on the added noise. That is because the amplitude (A) we choose is suprathreshold to the intrinsic frequency but subthreshold to the Canard frequency. According to our research results, when the external frequency gets the intrinsic one with all values of D from 0 to 0.4 (step size is 0.001), for $N = 3$, 10, 30, ,50, 70 and $N = 100$, $A = 0.013$ will cause suprathrehold oscillations while $A = 0.011$ is a subthreshold value (the simulation results will not be presented here). So if we choose the one that is subthreshold (e.g., $A = 0.011$) to the intrinsic frequency, it will be too far to evoke Canard resonance ($A \le 0.357$ will not produce Canard oscillations) no matter whether the noise is small or intense. So in this paper, the amplitude is selected to make the two resonances

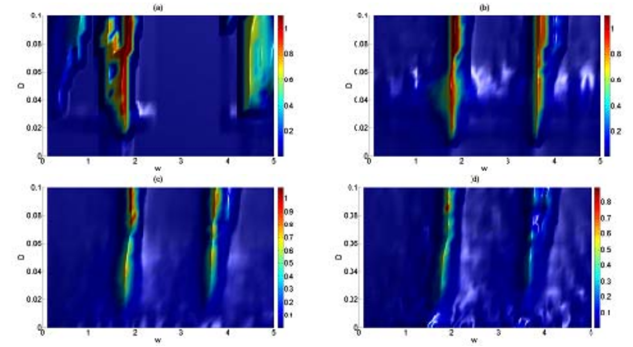

Fig.6 Graph of $\omega - D - S$: (a) $B = 0, N = 30$. (b) $B = 0.002, N = 30$. (c) $B = 0.005, N = 30$. (d) $B = 0.01, N = 30$.

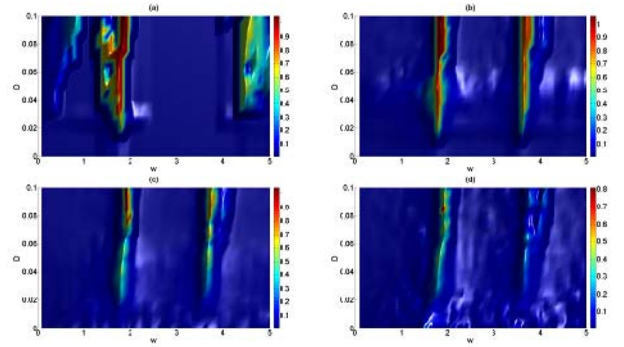

Fig.7 Graph of $\omega - D - S$: (a) $B = 0, N = 50$. (b) $B = 0.002, N = 50$. (c) $B = 0.005, N = 50$. (d) $B = 0.01, N = 50$.

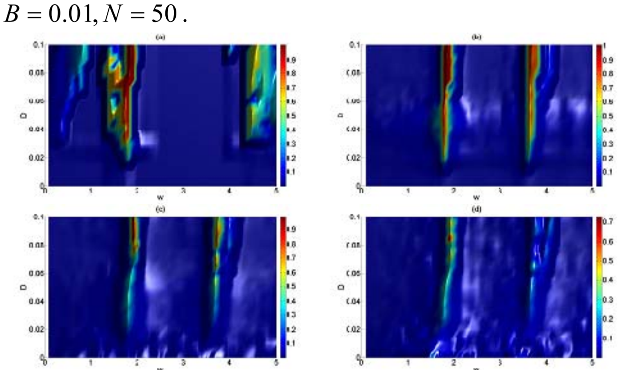

Fig.8 Graph of $\omega - D - S$: (a) $B = 0, N = 70$. (b) $B = 0.002, N = 70$. (c) $B = 0.005, N = 70$. (d) $B = 0.01, N = 70$.

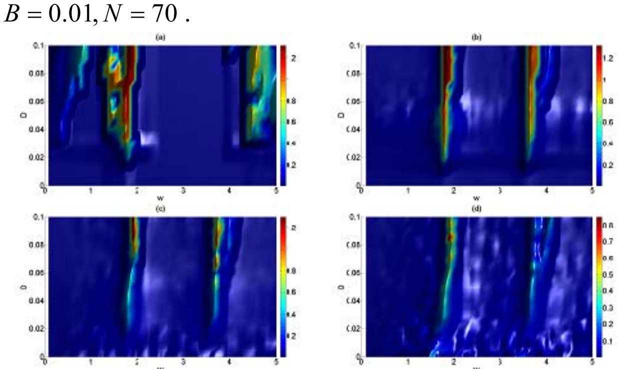

Fig.9 Graph of $\omega - D - S$: (a) $B = 0, N = 100$. (b) $B = 0.002, N = 100$. (c) $B = 0.005, N = 100$. (d) $B = 0.01, N = 100$.

(intrinsic frequency and Canard frequency induced resonances) emerge explicitly with help of white noise. Peaks in the graphs at the internal frequencies explain the fact that adding the driving force at the Canard or intrinsic frequency can be successfully used in the improvement of a signal receiving, even if the information is carried by another low frequency.

The maximum SNR at the intrinsic frequency is not caused by the adding noise, but by the resonance that the external frequency matches the intrinsic one of the system. It is a kind of resonance emerges when external signal is at the intrinsic frequency of affected system, and when adding white noise in if with subthreshold periodic stimulus, SR could take place in the neighborhood of the intrinsic frequency, namely, the first red or orange areas in the color maps 4 to 9 which also present the intrinsic frequency could be affected by the coupling strength, but not be influenced by the number (N) of neurons in the network system. When the frequency of external periodic stimuli approaches to the Canard frequency, the system is forced by the added noise and the subthreshold periodic stimulus to produce Canard oscillations at the fix point and with the optimal noise added in, it shoots the most intense Canard oscillations. And in the background of noise, once the external frequency gets the value of Canard frequency, SNR will reach the maximum value. Notably, when at Canard frequency, there exists an optimal intensity of which the added noise will cause the most intense Canard oscillation as well as the most effective signal transmission in the chain, that is so called Canard enhance SR. Also, similar with the situation of intrinsic frequency, the number of neuron in the chain couldn't affect the Canard frequency of the system, but the coupling strength could change it slightly. With the number of neurons in the network increased form 3 to 100, the frequency of stimuli should approach the internal frequencies of the system more closely to produce the resonance phenomenon, otherwise, it will be very difficult to appear.

Therefore, it owns an instructive meaning to acupunctrue therapy: due to the discrepancy of individual patient and diseases, the stimuli frequency of acupuncture manipulation should be different in order to meet with the internal frequencies of the patient, i.e., because of the internal frequencies of the individual patient, effects of the therapies used with manipulations at same frequency are different. Experimental results which follow the steps of biotic experiment shown in Fig.2 are presented in Fig.10. With the frequency of manipulations altered, the outputs of the transmission path (from tsu san li point to spinal dorsal horn) explicitly emerge a certain kind of resonance, it is in accordance with our results of the simulations of the chain network of FHN neurons. According to averange power (AP) of the evoked time series, twirling manipulations at the frequency of 50, 100, 150 is almost in the same leval, while at the frequency of 200, the AP value apparently exceeds the fromer three, and that may suggest the frequency of 200 approaches the internal frequency, e.g., the intrinsic or Canard frequency, more closely. Noteworthy, due to the frequency selectivty, the external frequency which is away from the internal ones will not cause the model to fire. However, differently, manipulations at frequencies of 50, 100, 150 evoke spikes in the target organ. Moreover, from the following graph, APs of the evoked spikes at the frequencies of 50, 100, 150 stay at the same level, just like Q s in the chain model being zero at the external frequencies far away from the internal ones. Noteworthy, doctor could hardly take the manipulation whose frequency exceeds 200.

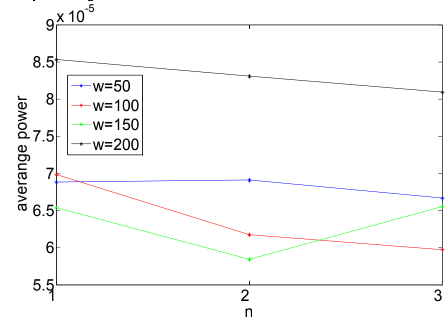

Fig.10 The corresponding time series of spikes in the spinal dorsal horn due to the four different manipulation frequencies, n is the serial number of experiment.

IV. CONCLUSIONS

From our work, the internal frequencies of the chain network of FHN neurons include two different frequencies, namely, the intrinsic and Canard frequency which are of different values. When the frequency of added periodic stimuli meets these two internal frequencies, the transmission of signal processing in the system will be enhanced. The mechanism presented here which bases on the chain network of FHN neurons could used to interpret the experimental observations in twirling manipulations at tsu san li point and shed further light on understanding biological information processing. We also find some quasi resonance phenomenon in the transmission of acupuncture signals at different frequencies in the creatural experiments.

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