Modulation of stimulation frequency of afferents of the spinal cord from the same site and intensity can induce a variety of movements

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Abstract

In this report we shall review the finding that selective stimulation of tibial nerve large afferents and selective stimulation of lumbar sacral afferents to the spinal cord can elicit modification of motor output only by changing of the rate of the train of stimuli without changing the stimulus strength or site of stimulation. After a brief description of the applied methods in reported studies of suppression of sustained anti-clonus by train of stimuli of large afferents of tibial nerve at the sensory level, we shall point out that this “anti-clonus” effect depends from a particular frequency range. Other study in which we shall illustrate dependence from frequency rate of motor output it is epidural or transcutaneous stimulation of lumbar posterior roots; and how the frequency of applied stimulation trains can induce two completely different functional outputs of paralysed lower limbs (standing and locomotor-like movement) due to upper motor neuron lesion.

At the end we shall discuss underlying mechanisms of this artificial “coding” in order to induce movement by afferent FES. Finally we shall discuss the significance of these findings for clinical practice of FES in upper motor neuron disorders.

1 Introduction

From the early beginning of FES frequency of stimulation of peripheral nerves in order to elicit functional movement by activating paralyzed muscles has been focused towards elicitation of sufficient muscle power. Therefore the used frequency was determined by fusion of muscle twitches to the steady and strong movement [1]. However, it has been noticed that stimulation of peripheral nerve trunks in addition to depolarisation of motor axons and induced proprioceptive muscle input by contraction of otherwise paralyzed muscles was also effect of stimulation of the largest diameter sensory fibers of the nerve trunk with lowest threshold for depolarisation by a train of stimuli [2]. This observations, that peripheral nerve trunk stimulation can have direct motor effect and indirect reflex afferent (sensory) – efferent (motor) effects, led researchers to study optimal frequency for muscle force generation and optimal frequency for augmentation of neural control. In this presentation we shall focus on “sensitivity” of central nervous system and its sensory – motor mechanisms to modulation of frequency while modifying movement.

We shall use two examples to illustrate the main point of our presentation dependence of movement modification by changing frequency of the train of stimuli.

Example 1: Clonus is a term describing repetitive stretch reflex of any muscle group of the human body with a frequency between 6 and 7 Hz. Clonus can be present in adult persons with intact nervous system after setting volitionally or by extraneous muscle exercise in healthy people it is a known observation that clonus will appear after hours of mountain climbing. However in patients with neurological conditions, after stroke, head and spinal cord injury, multiple sclerosis and others, clonus can be an obstacle for those patients standing, walking and other daily activities, even for use of wheelchair.

From neuro-physiological point of view the underlying mechanism for clonus is an increased central state of excitability of segmental mechanisms involved in motor cells, motor nuclei and functional disbalance in reciprocal inhibition between agonist and antagonist muscle. In case of ankle clonus motor cell excitability of triceps sure muscle group is higher than motor cell excitability of dorsal flexors of the ankle (tibial anterior and other muscles).

Fig. 1 is showing a sketch of described agonist and antagonist segmental levels of leg muscles and illus-
trate an attempt to suppress ankle clonus by increasing reciprocal inhibition by stimulating at the threshold for large afferents of peripheral nerve and causing the increase of reciprocal inhibition to the motor neurons of hyper-excitabile triceps surae muscle.

Effect of this stimulation is illustrated in Fig. 2. Anticlonus effect was clear and repetitive when applied train of stimuli of 75 V with 1ms duration of the single stimulus within a 50 Hz train of 0.4 s. Nevertheless such clear effect was absent when frequency of train was of the same strength but lower frequency of 30 or 40 Hz [3, 4].

“Anti-clonus effect” depends from different stimulation parameters. Naturally this effect will not be present in every testing subject with same parameters since this is not a “wired” sensory motor integration activity but a dynamic response to externally controlled input. What we are learning is if our attempt is to induce reciprocal inhibition and establish equilibrium between antagonistic motor nuclei we should not only examine the effect of one frequency, but at least several of them within a range of 30 to 100Hz.

Example 2: Another reported illustrative example is selective stimulation of lumbar-sacral posterior roots in people with chronic posttraumatic spinal cord injury and known as a ASIA A or B between clinicians. Placement of multi-site epidural electrode can elicit selective stimulation of posterior roots and such studies of Vienna group for restoration of locomotion in Otto Wagner Hospital, Wilhelminenspital and Center of Biomedical Engineering and Physics [5, 6, 7, 8] demonstrate that application of different frequencies of train at the same stimulus site and strength it is possible to elicit movement of paralysed lower limbs similar to strong standing are locomotor-like movement. Fig: 3 is illustrating this finding.

Fig. 1 Anti-clonus model. Clonus in triceps surae (detected by electromechanical or bioelectrical clonus detector) triggers stimulator, which delivers stimuli to afferent fibers of peroneal nerve. These evoke slight contraction in tibialis anterior muscle, and at the same time inhibit clonic activity in antagonistic triceps surae muscle [3, 4].

Fig. 2 Dependency of the anti-clonus effect upon frequency of the stimuli within the train. This proves that the effect of stimulation is highly specific [3, 4].

Fig. 3 Surface electrode recording from lower limb muscles of a paraplegic patient while stimulating epidurally posterior roots L2-S1. We are showing in the same subject without changing site and strength of stimulation we can modify feature of motor output from locomotor-like to extending lower limbs of standing-like posture [5, 6]; Vertical markers: 500 μV (Q, H, TA, TS); 45° (KM knee movement). Horizontal marker: 1 s

We can see that rhythmical and tonic EMG activity of paralyzed lower limbs induced by spinal cord stimulation can be elicited and 31 and 21 Hz can induce strikingly different motor outputs of rhythmical activity when compared to 16 and 10 Hz of tonic activity [7, 8]. Moreover the goniometer traces illustrate the corresponding rhythmical and extension movements, respectively. We would like to emphasise that stimulation parameters (site and strength) were never changed during the recording session. Note that during the “flexion phases” induced at 31–21 Hz the amplitudes in quadriceps and tibialis anterior are larger than the ones in hamstring and triceps surae, respectively. This dominance is reversed in response to stimulus frequencies of 16–10 Hz. Recorded in a complete SCI subject (estimated segmental level of stimulation: L4/5); stimulation parameters: 10 V, 210 μs pulse width.
2 Discussion and Conclusion

Let us initiate discussion and conclusion by analysing Fig. 4 which is a sketch of interneuron human lumbar grey matter network and superimposed drawing of spinal reflex pathways with different numbers of interposed inter-neurons between afferent and efferent parts of the reflex arc. Described finding led us to develop the working hypothesis that depolarised primary afferent fibers have connectivity with monosynaptic, polysynaptic and interneuron networks. When changing the repetition rate of input parameters, the interneuron network can respond with different configuration of subunits of the motor output generator. Therefore “coupling” and “discoupling” of human lumbar cord interneurons by different frequencies is at presence proposed mechanisms under testing. Further work should demonstrate how much functional movement can be elicited by modifying frequencies in interaction with human motor control with intact or impaired CNS in order to become useful in the clinical practise.

3 Literature


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