Combined application of Magnetic and Electric Stimulation

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Abstract

Electrical stimulation has been known since Galvani's work with frogs in the 1780's and is the most widely used method of stimulation in modern clinical medicine. Magnetic stimulation does however have certain advantages over electrical stimulation including its ability to stimulate nerves painlessly. It appears a natural progression to try a method of combined magnetic and electric stimulation. This could potentially combine the advantages of the two methods and minimise or negate their disadvantages. In particular it may improve the focality of magnetic stimulation to that when used alone.

1. Introduction

Unlike electrical stimulation, magnetic stimulation is painless [Barker (1987)]. The reason is that magnetic fields pass through all body structures unattenuated. Electrical stimuli are attenuated and therefore require a much greater intensity at the surface to stimulate structures in the body. The pain fibres are located close to the surface and are stimulated by these high intensity stimuli. Magnetic stimulation working at a lower intensity does not stimulate these structures.

Electrical stimulation is difficult (without extreme pain and/or the use of inserted needle electrodes) to achieve on certain structures deep in the body or located in bone [Hallett and Cohen (1989)]. As magnetic stimulation is not attenuated it can access these deeper structures. It is also non-invasive and non-contact and hence does not require any special skin preparations such as application of electrode gels.

Magnetic stimulators are bulky in size when compared to electrical stimulators and they have low repetition rate (between ¼ and 1 Hz depending on pulse intensity). This low rate is due to the high energies required for magnetic stimulation (typically greater that 100 amps).

The site of stimulation does not have to be as precise for magnetic as electric, as the resulting magnetic field covers a broader surface area. This can have certain advantages, however when carrying out experiments such as with nerve conduction studies it is essential to know the exact site of stimulation. Electrical stimulation affords much greater accuracy in focality (localisation of point of stimulation) and for this reason is the preferred method in such clinical studies.

2. Combined Magnetic and Electric Stimulation of Peroneal nerve

The technique of 'magnetic-electric stimulation' has been previously tried [Brickford et al 1987)]. Their results showed enhanced response using the two stimulators

simultaneously, with conduction nerve signal amplitudes of two to four times greater than the response using the two stimulators separately.
Upon study of a nerve recruitment curve it is agreed that as stimulus intensity is increased more nerve fibres are recruited until all are firing, corresponding to the point of maximal response. If the stimulus intensity is increased above a threshold level (typically 80 volts) the response will be several times greater than at threshold value. Thus if a portion of currents from both stimulators combine together, it is clear that the response will be significantly greater than either in isolation.
In the course of the work presented in this paper an experimental design was set up combining use of a Dantec M2 magnetic stimulator and a Dantec Cantata EMG machine (to record response, together with a Medelec NS6 electrical stimulator. The M2 magnetic stimulator is capable of discharging from a capacitor bank of value 826 μF, at voltage levels up to 1500 volts, while the NS6 electrical stimulator can provide stimuli of up to 300 volts in amplitude.
For the experiment to be valid, the stimulating pulses should arrive either simultaneously or with a small fixed time delay between them. It has been shown that if a sub-threshold pulse has been applied, the threshold for stimulation by a subsequent second pulse will be reduced for a brief period, typically less than one millisecond [de Paor and Murray (1994)].
Following upon various experimental test procedures, a cmos electronic switch (4057) was found suitable in providing a constant delay between the two pulses. The time difference between stimuli due to internal delays in the stimulators was of the order of one millisecond. The electrical stimulator has a delay facility, which allows the stimulator to be delayed for a specific period following the initial trigger. This was used to ensure that the stimulating pulses coincided.
A method was designed to allow both stimulators be held in place without movement and without impeding upon each other. The *peroneal nerve* in the leg was chosen with the measurement electrodes placed on the *tibialis anterior* muscle. The leg was rested on a cushion to help avoid movement artefact interference.

3. Experiment Procedures and Results

Measurements were recorded as peak to peak readings of the recorded signals from the measurement electrodes. In order to ensure reliability the experiments were repeated on five different subjects, three male and two female with ages ranging between 20 and 30 years. Measurements were taken in suitable voltage increments using electrical stimulation between threshold level and a level that produced a maximal response or discomfort (a threshold response is the lowest noticeable response and a maximal is the maximum possible response). At each level of electrical stimulation measurements were taken using different levels of magnetic stimulation at 150-volt increments of capacitor voltage from 300 to 1350 volts. Each measurement was repeated five times and the average result calculated.
The combined stimulus response was greater (by more than a factor of four) to that achieved by using the stimulators separately. The time location of peaks was seen to be same for each stimulator. This demonstrates that the combined method is focal.

Attempts were made to model the interaction between the two stimuli, based on a linear single-input, single-output, control system, with parameters *gain* and *offset*. The model approximates the response to electrical stimuli using a straight-line approximation, designed to operate between the threshold and maximal response levels only. This can be stated mathematically by the equation

$$resp = gain * (elec) + offset \qquad \text{(i)}$$

where *resp* = normalised nerve response, *elec* = normalised electrical stimulus over the region of the model, and *gain* and *offset* are system gain and offset respectively.
It was necessary to include additional factors to account for variation in the level of magnetic stimulation. Two additional straight line models were used, with the level of magnetic stimulation being the input variable and gain and offset the output variables. This produced four parameters, α, β, γ, and δ, which can be used to find the gain and offset for any particular level of magnetic stimulation by using the following equations;

$$gain = \alpha * (mag) + \beta \qquad \text{(ii)}$$

$$offset = \gamma * (mag) + \delta \qquad \text{(ii)}$$

where *mag* is the normalised value of magnetic stimulus intensity.
The values of α, β, γ, and δ were calculated for each set of subject data, using a least squares curve fitting method. From these values the nerve response can be predicted for any given levels of magnetic and electric stimuli.

Results achieved showed that the model is a close representation of the measured system.
Following upon an analysis of data values obtained from the model, it was observed that

1. The gain of the system (i.e. effect of electrical stimuli) decreases in all cases for an increase in the level of magnetic stimulation
2. The offset in the system increases as the level of magnetic stimulation increases.
3. There was only one case (out of a total of fifty calculations) in which the gain of the system was negative, i.e. where an increase in electrical stimulus intensity caused a decrease in output from the system. This decrease was less than 2% of the maximum and occurred at maximal levels.

From these observations it is clear that the two types of stimuli do interact, and indeed constructively (producing an increased response).

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