Communication

Methodology for the quantitative assessment of human crossed-spinal reflex pathways

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1 Introduction

THE STUDY of reflexes has long been accepted as a potent means by which to study neuromuscular integrity in man. By using reflex protocols, the researcher is equipped with a noninvasive means by which to study spinal cord excitability. Early attempts to quantify the reflex response were burdened by inadequate measuring techniques. The photomotograph (GIBSON, 1959; TUCK, 1974) and the Lawson kinemometer (MOLCHO and RECHEF, 1970) provided a rough measure of tendon reflex response. It was not until the early 1970s that investigators began to partition the tendon-tap reflex into its central latency and peripheral muscle (or motor time) components (HAYES, 1972; KROLL, 1974). Most studies to date have used the fractionated reflex time model when assessing neuromuscular integrity in man (KROLL, 1974). While the latency and motor time results obtained by this method provide some useful information, a more complete measurement scheme must include the isometric force response of the reflex.

Another shortcoming of previous studies has been the fact that they have been limited, in most cases, to the study of unilateral reflexes. Little attention has been devoted to the understanding of crossed-spinal pathways in the development of reflex models. It appears tenable that a complete understanding of spinal cord organisation must, at least, include the influence of ipsilateral and contralateral input on spinal function.

This communication reports on the development of a conditioning reflex apparatus for the examination of the effects of contralateral and ipsilateral conditioning inputs on reflex function. Both the mechanically induced tendon-tap and the electrically evoked Hoffmann reflexes can be examined with this apparatus. Also, the isometric force response of the reflex can be examined. Section 2 of this paper reviews this technique for examining reflex function, and Section 3 describes in detail the apparatus, instrumentation and software developed for the implementation of this assessment paradigm. Section 4 briefly describes pertinent results to date utilising this measurement model, and Section 5 presents our conclusions.

2 Technique

In our laboratory, to gain a more sensitive model of reflex function, we use the force/time characteristics of the reflex response. Fig. 1 shows a typical force/time curve obtained from a tendon reflex response. By measuring the isometric force of the reflex, the response can be fractionated into additional components. The complete model is summarised below.

EMG latency EMG_{lat} is defined as the time between the tendon-tap stimulus and the beginning of muscle activity, just as in the fractionated reflex time model. Force latency F_{lat} is the amount of time it takes the system from the beginning of the stimulus until the first sign of force application is recorded. Electromechanical delay EMD is the

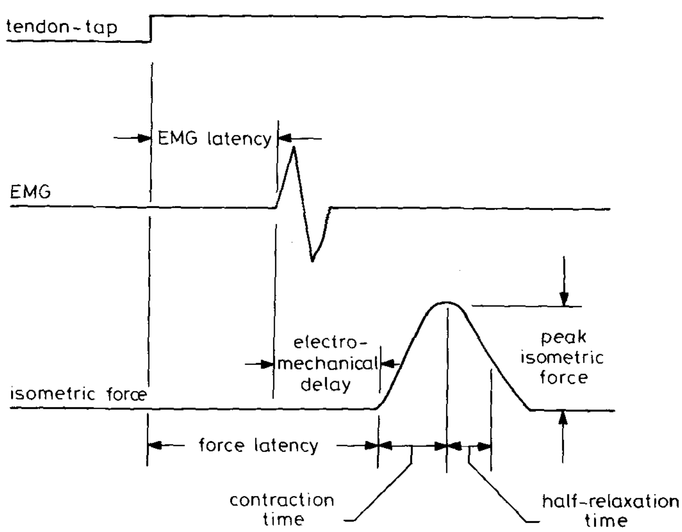

Fig. 1 *Force/time curve analysis of a tendon-tap reflex response. This model provides a sensitive measure of neuromuscular integrity*

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amount of time between the beginning of muscle activity and the first sign of force application. Contraction time *CT* is the time from the beginning of force application until such time that peak force is achieved, and peak isometric force *PF* is the maximum amount of force in newtons exerted during the trial.

Half-relaxation time ($i/2 - RT$) provides an indication of the relaxation properties of the muscle involved, and includes the time from peak isometric force until one-half this value is achieved. In addition to these direct measures, isometric impulse *IMP* and integrated EMG *IEMG* are calculated. The inclusion of *CT*, *PF*, ($i/2 - RT$) and *IMP* measures into this model provides the researcher with a more sensitive tool with which to study neuromuscular integrity in man.

3 Design

3.1. *Apparatus*

The conditioned reflex apparatus is shown in Fig. 2. This apparatus is a modified Elgin table, with a fully padded back-rest and seat. The back-rest is adjustable from a position of 90° to approximately 130°. The seat is equipped with a hand crank to adjust it forward and backward (approximately 40 cm) to accommodate tall and short subjects. At the bottom of the apparatus is the carriage which slides along the length of the front half of the apparatus and is provided with a locking mechanism. The foot plate assembly is mounted at the rear within this carriage and is designed to permit vertical adjustment (approximately 25 cm), again to accommodate both tall and short subjects. On the top of the carriage is mounted the solenoid/loadcell platform. This platform has four locking clamps which provide horizontal adjustment (approximately 30 cm) as well as rapid removal of the platform.

The tendon-tap stimuli are delivered by a pair of electromagnetic solenoids. Each solenoid is held in position by a multiple-degrees-of-freedom yoke assembly and is fitted with rubber hammers. This flexible design provides 2 cm horizontal adjustment, 10 cm vertical adjustment, and a ±30° tilt range for tendon impact angle. This feature is used when testing a subject whose leg is in a flexed or an extended position. In addition to the yoke adjustments, the carriage mounting system provides more than 15 cm horizontal adjustment range.

The isometric force for each reflex is recorded with a loadcell (0–50 lb (0–23 kg) range). The configuration for testing the isometric force response of the patellar and Achilles tendon-tap reflex is also shown in Fig. 2.

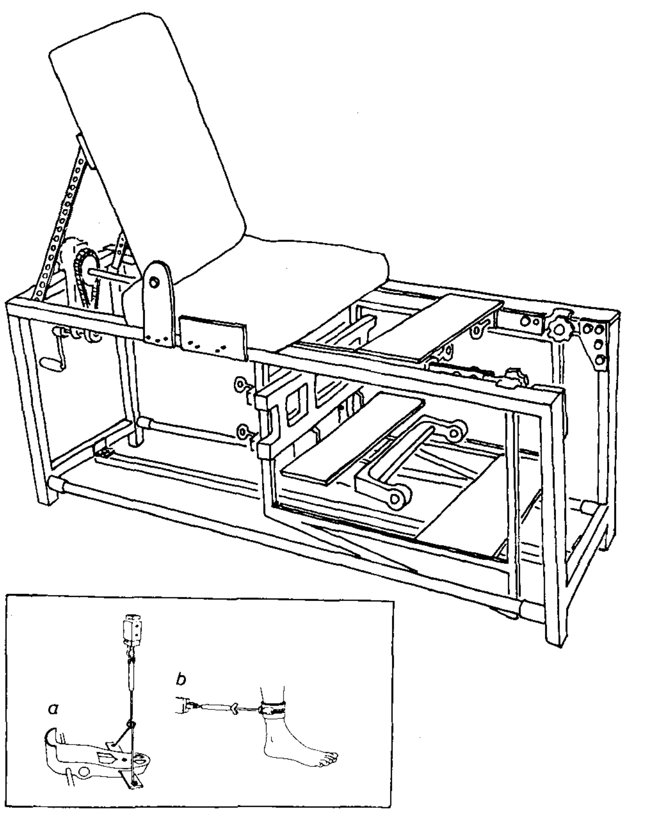

Fig. 2 *Conditioned reflex apparatus. Note the arrangement to examine the isometric force response of (a) plantarflexion; and (b) knee extension*

3.2. *Data-acquisition system*

The data-acquisition system consists of an IBM AT computer configured with 1 *M* byte RAM, an 80287 co-processor, a 20 *M* byte hard drive, and two floppy drives, a 360 k byte and a 1·2 M byte. Hard copy is provided on an Epson FX80 printer, and a serial port is available for uploading tests to a mainframe computer. The display employed provides CGA or high-resolution (1280 × 800 pixels) operating modes (Amdek model 1280, or the Wyse technology WY-700). Drivers for the display were written in assembly language (*IBM*, 1984*a*; *b*; *Amdek*, 1986; *Wyse Technology*, 1985; HASKELL, 1986). The IBM computer is also equipped with both an analogue input (A/D) card (Data Translation DT2801a) and a digital I/O (DIO) card (Data Translation DT2817) (*Data Translation*, 1985). The A/D is configured for bipolar (±10 V) signals, and the input lines are brought out at a BNC patch panel on the signal-conditioning rack. The digital I/O lines are buffered and available on the instrument rack at a screw terminal panel. Fig. 3 shows a block diagram of the stimulus delivery system.

3.3 *Stimulus delivery*

The tendon-tap solenoids (Trombetta model Q-514-a8, 105 V DC) have a 15 mm travel distance. They are fitted

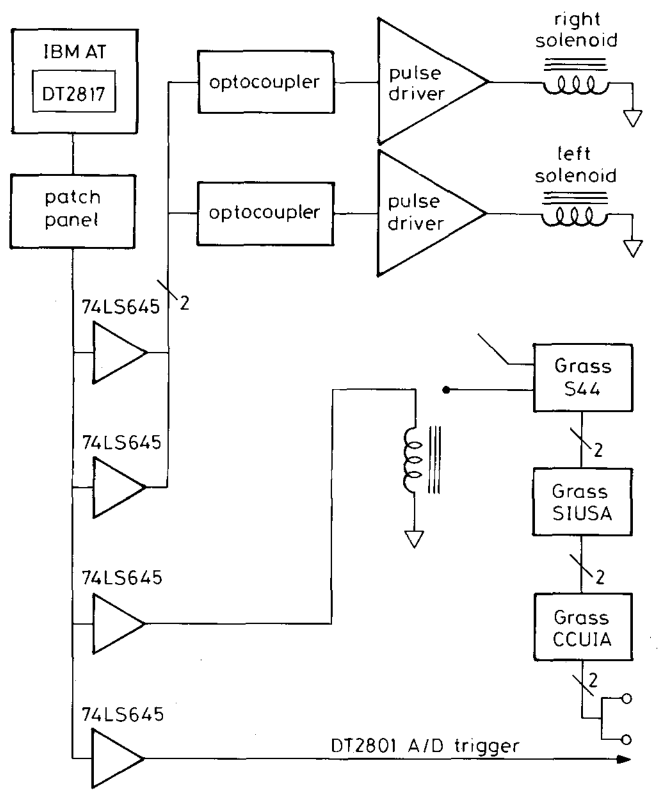

Fig. 3 *Block diagram of the stimulus interface system*

with rubber cushions to reduce impact in the event of overshoot in a no-load situation. The solenoids are driven with a power FET device gated with a 5 ms nominal pulse provided by a monostable multivibrator. The monostable pulsewidth is adjustable through a range of 2–10 ms and is triggered from the digital output panel via an optoisolator. A schematic diagram of one-half of the solenoid driver circuit is shown in Fig. 4. Mechanically in series with each

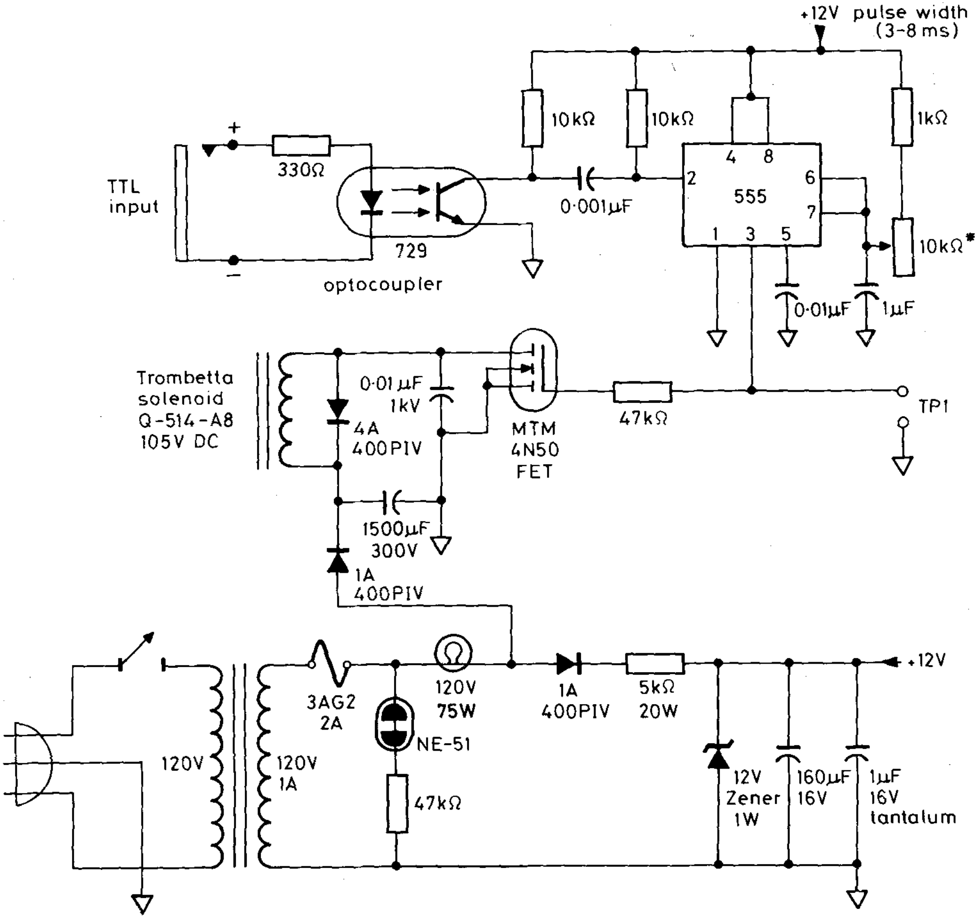

Fig. 4 *Schematic of solenoid driver (one-half of pair)* **pulse width adjustment* *PIV: peak inverse voltage*

solenoid shaft is a dual-element ceramic piezotransducer. These transducers provide accurate measurements of the hammer tap forces. Columbia model 9010 charge amplifiers, with auto-zero and precise calibration features, amplify the piezo output to a level suitable for driving the data-acquisition card (DT2801a) (*Data Translation*, 1985). Low-pass filtering for the sampling is not incorporated due to the inherent response limitations within the mechanics of the tendon-tap system.

The Hoffmann response is elicited with an electrostimulator (Grass model S88) triggered through a relay from the digital output panel. The output of the stimulator is fed through an isolator (Grass model SIU5A) and then through a constant-current unit (Grass model CCU1A) to ensure safe stimulus delivery. Appropriate stimulus parameters for this paradigm have previously been described (HUGON, 1973).

3.4 *Data acquisition*

The reflex paradigm is controlled by the IBM AT via a computer program entitled CRP (Conditioned Reflex Paradigm). The CRP program is written in Microsoft QuickBasic 4.5, which provides a complete program development environment (*Microsoft QuickBasic*, 1988; 1989). QuickBasic is particularly suitable for applications requiring substantial real-time operations which require direct memory and bus I/O access.

3.5 *Automated data segmentation*

The function of the processing algorithms is to extract inflection points and to segment the waveforms for timing calculations. In consideration of the time restrictions of this online processing of the data between trials (<30 s), optimisation and careful selection of the algorithms employed is of primary concern. Data waveforms are segmented and selectively searched and processed. Digital filtering is avoided when possible. Noise and spurious pulse rejection heuristics are utilised in the location of inflection points. Filtering is applied only in a very narrow window of the waveform peaks of interest. In the area of onset inflection points, linear and polynomial regressions are applied to fit the data based on *a priori* 'idealised' waveform descriptions.

The positive peaks of the tendon-tap forces [providing additional comparative information (STAM and VAN LEEUWEN, 1984)] are found with the assistance of the ISI which is known, and an estimate of the mechanical delay. Owing to the robust nature of these waveforms, peaks are detected with a simple maximum-value technique.

EMG waveforms are marked for onset, positive and negative peaks. The location of EMG peaks are first estimated based on the reflex stimulus peak location. Again, a simple min-max search and heuristics for spurious peaks provides robust times. The onset of EMG activity is calculated with the aid of a linear regression estimate of the zero-crossing. The regression parameters are based on the waveform between a point at 80 per cent of the peak value and 10 per cent of that value. The onset is then defined as the zero-crossing point. Reflex-force onset is problematic due to the tendon-tap stimulus artefact. A third-order polynomial regression model permits a robust estimate of the zero-crossing point based on a data segment located in a manner similar to that employed in the EMG technique outlined above.

4 Results

In our laboratory, we have collected data from several studies using the conditioned reflex apparatus (KAMEN and KOCEJA, 1989; KOCEJA and KAMEN, 1988; 1989; KOCEJA *et al.* 1989). Statistical reliabilities of the dependent measures have been consistently high ($r > 0{\cdot}70$), with the reflex torque measures providing the highest reliabilities ($> 0{\cdot}90$). These reliabilities are trial-to-trial reliabilities, indicating that the dependent measures are highly consistent within a test session. Also the validity of the peak torque values derived with this system can be inferred by comparing the changes in peak torque with the changes in surface EMG activity. Fig. 5 summarises some of these results using the tendon-tap paradigm and the H-reflex paradigm. From these results it can be seen that, while motoneuron excitability as evidenced by integrated EMG activity is changing as a result of conditioning inputs, so too are the peak torque values.

The use of this assessment paradigm allows one to examine such IEMG/force relationships across a variety of conditions, and to determine whether differences in the time course of these changes exist for specific subject groups. For example, recent data suggests reliable and consistent differences between aged individuals and normal controls in peak torque values, with concomitant changes in EMG activity (KAMEN and KOCEJA, 1989). Moreover, these changes are evident for both unilateral and conditioned reflexes. Pertinent future research questions would involve investigating the mechanisms responsible for these changes. It is believed that the use of this paradigm will be influential in determining these mechanisms. Answers to these questions will undoubtedly uncover much about the organisation of segmental reflexes.

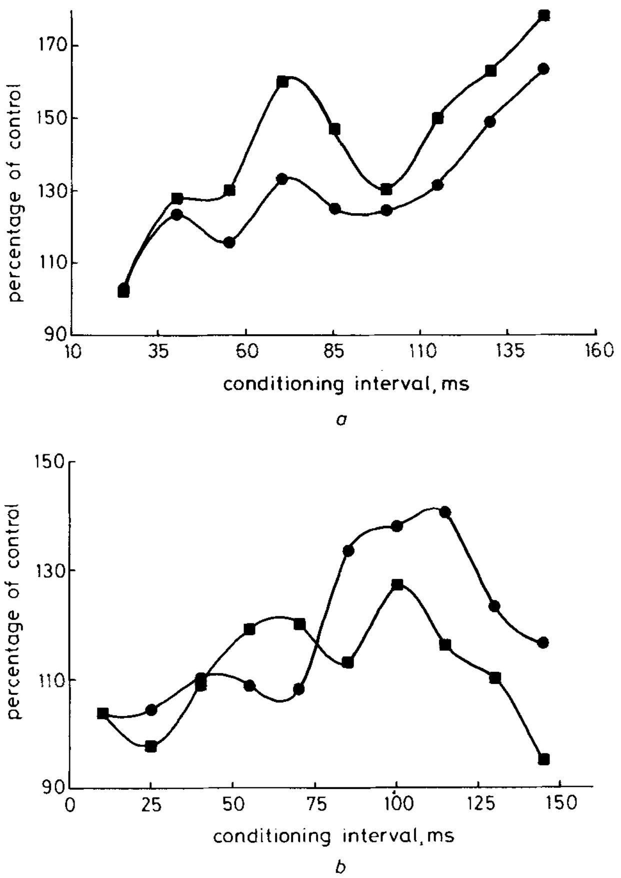

Fig. 5 *Summary of results obtained with the conditioned reflex paradigm. (a) Patellar tendon-tap reflex that is conditioned with a tap to the contralateral patellar tendon; and (b) tibial nerve H-reflex conditioned by a contralateral tibial nerve H-reflex. Results are plotted as a percentage of the unilateral reflex response; conditioning interval represents the time in milliseconds between the conditioning stimulus and the test reflex. Note the close correspondence between integrated EMG and peak torque in both conditions*
●—● *peak torque*
■—■ *integrated EMG*

5 Conclusions

It can be concluded that this automated conditioned reflex paradigm is a valid and reliable tool for assessing spinal cord excitability in humans. By using this system, the integrity of crossed-spinal pathways can be determined. Moreover, by using the isometric force recording of the reflex response, a more sensitive measure of neuromuscular integrity is obtained. We conclude that such a paradigm is useful for understanding the complexities of crossed-spinal reflex function, and will provide researchers in the area of motor control with a noninvasive, yet sensitive assessment tool.

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