THE USE OF SOMATOSENSORY EVOKED POTENTIALS FOR THE DETERMINATION OF SENSORY NERVE CONDUCTION VELOCITIES

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GRAHAM JOHN BALL.

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ABSTRACT

Title: The Use of Somatosensory Evoked Potentials for the Determination of Sensory Nerve Conduction Velocities.

Author: Graham John Ball.

In 1947 Dawson[17] first recorded a somatosensory evoked potential after electrically stimulating the ulnar, median and lateral popliteal nerves. Giblin (1964[27]), using improved techniques, reported an initial negative wave at 14 to 18 msec. followed by a positive potential peaking at 23 to 31 msec.

Using the peak of the first negative wave or the beginning of the positive wave and the peak of the first derivative of the downsweep of the positive wave as latency markers, the sensory conduction velocities of the ulnar, median, peroneal and posterior tibial nerves were measured. The variance of the background noise was used as an indicator of the amplitude of background noise. Statistical tests were performed upon the data to test the randomness and independence of the data. Intraindividual consistency tests were conducted and some tests for distribution of the evoked potential over the scalp were made. Nerve conduction velocities of three clinical patients showed the applicability of the test to aiding clinical diagnosis of sensory nerve problems.

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LITERATURE REVIEW

As far back as 1762, Sauvage[33] arrived at a velocity of the nerve impulse of more than 100,000 metres per second. It was not until 1908 that Piper [54,55] used the muscle action potential in man as an indicator of the arrival of nerve impulses by stimulation of the median nerve at two points and arrived at a motor conduction velocity of 60 to 65 metres per second. The first successful attempt to record percutaneously from a mixed nerve in situ was made by Eichler (1938[25]). Dawson and Scott (1949[22]) used the same procedure and obtained a far better resolution by photographically superimposing 50 traces. Their attempts to measure the conduction velocity proved unsuccessful. The failure was attributed to the difficulty of obtaining pairs of records which had the same shape from electrodes on different sites of the nerve. Dawson (1956[21]) recorded the first purely sensory nerve action potentials. He stimulated the digital nerve and recorded an action potential at the wrist and elbow. Gilliatt and co-workers (1961[28], 1958[29], 1962[30]) recorded sensory conduction time as a diagnostic aid to investigation of patients with peripheral nerve lesions.

In 1947 Dawson[17] conducted an experiment electrically stimulating the ulnar, median, and lateral popliteal nerve and received, after superimposing 50 sweeps, an evoked potential over the corresponding contralateral sensory areas of the central gyrus. The short latency between the beginning of the response of the order of 18 to 20 milliseconds suggested that the response indicated events occurring in the cortex, at, or soon after, the time of arrival of afferent volleys to the cortex. Dawson also indicated that the shorter latency of evoked potential went with a shorter path taken by the impulse. A surface positive wave beginning at 19 milliseconds and which peaked 25 to 28 milliseconds after stimulus at the contralateral ulnar nerve at the elbow, possibly preceded by a small negativity of a few milliseconds duration, was reported by L-E Larson (1953[42]). The negative deflection peaking at 40 milliseconds and a second positive wave lasting 50 to 60 milliseconds was followed by a non-specific response. In Dawson's (1956[21]) recording of evoked potentials, after stimulation of the contralateral ulnar nerve at the elbow, he used the averaging method described by Dawson (1953[19], 1954[20]). He recorded the first significant negative deflection starting at 20 milliseconds, a positive beginning at 25 milliseconds and peaking at 28 to 30 milliseconds and reported 1 later phase.

The general form of this response, recorded by Goff et al (1962[31]) was consistent among subjects. The initial evoked activity, component 1, based on median nerve stimulation, was a triphasic, positive, negative, positive complex with peak latencies at 16 ± 2 milliseconds, the negativity sharply peaked 3 to 4 milliseconds later, and a positive peak at 25 ± 4 milliseconds which was not consistently detectable in all subjects. Components 2 and 3 designated two positive deflections while component 4 had a negative peak at 65 ± 14 milliseconds and positive peaking at 85 ± 20 milliseconds. This component 4 showed the greatest intra- and inter-subject variability in waveform. In 1964 Giblin[27] reported that in some subjects as many as 7 distinct components could be identified in the first 100 milliseconds of the evoked potential. The time elapsing between the stimulus at the contralateral median nerve at the wrist and the peak of each of the potentials within the first 35 milliseconds could usually be measured with an accuracy of ± 1 millisecond but there was considerable difference between the responses recorded in different subjects. The initial negative was followed by a positive potential which differed as to whether one or two brief positive potentials were recorded within the first 35 milliseconds following the stimulus. The initial negative potential began 14-18 milliseconds after application of the stimulus and reached a peak at 17.5 to 21 milliseconds. In Group V, a single

brief early positive potential followed the initial negative one. The latency of its peak ranged from 23 to 31 milliseconds with a mean of 26.8 milliseconds. In the second type of response, Group W, the records from these subjects showed two brief positive potentials separated by a negative going deflection which varied in prominence in different subjects. The first positive potential at 22.4 ± .04 milliseconds (range 22-23 milliseconds), was evoked by relatively weaker shocks and attained its maximum amplitude with shocks which were below the motor threshold at a time when the second was still barely visible. The second at 30.71 ± 1.50 (29-33 milliseconds), attained its maximal amplitude in these subjects only when the shocks evoked a definite motor response. Furthermore, increasing the intensity of the stimulus never caused a decrease of more than 1 or 2 milliseconds in the latency of the first positive potential but occasionally decreased that of the second by as much as 6 milliseconds. The two positive potentials could also be shown to have different potential fields on the scalp. The first positive potential was clearly seen in records from electrodes anterior and medial to the standard (electrode over "hand" area of post central gyrus) while the second was the more prominent from more posterior and lateral electrodes. These brief early potentials were followed by a series of later waves which were longer in duration and often greater in amplitude than the earlier components of the response but showed greater individual differences in latency and

in their relative prominence. A later negative wave and still later positive wave could usually be identified with confidence. In eight subjects the positive wave was followed by a still later negative wave resembling the negative wave preceding it. Thereafter, the individual variations were so great that it was difficult to distinguish which waves were comparable. Allison[4] reported that at approximately 17 milliseconds following the stimulus a small positive wave sometimes appeared followed by a clearly repeatable sharp negativity with a peak latency of very nearly 20 milliseconds followed at 22 to 23 milliseconds by an equally positive wave designated 1. The positive peak was clearly defined in some subjects, in other subjects it appeared as a notch or inflection on the larger succeeding positivity. This was followed by a complex diphasic positive wave designated 2, and 3, a negative positive wave designated 4 and a negativity followed by a large positivity designated 5. S. J. Larson et al[43] reported a latency of the first portion of the response was usually between 15 and 20 milliseconds with median nerve stimulation and 30 to 35 millisecon ds when the siatic nerve was stimulated. Uttal and Cook[61] have divided the evoked potentials into M,N, and O waves with latencies of approximately 20, 30, and 50 milliseconds respectively. Dawson[17] first reported an initial positive wave at 22 to 23 milliseconds after stimulation of the ulnar nerve at the wrist but later (1954[20]) he reported that the first positive

might be preceded by a small negative potential. Giblin[27] in his series of experiments showed an initial negative potential to be a consistent feature of the response evoked by stimulation of any of the nerves of the upper extremity. Allison (1962[4]) and Goff et al (1962[31]) have in fact, reported that in addition to an early negative potential with a latency similar to that reported here they at times recorded a still earlier positive potential with a peak of 16 ± 2 milliseconds.

The distribution of the evoked potential over the skull was examined by a number of investigators. Goff et al (1962[31]) examined the waveform and distribution of evoked activity occurring within 500 milliseconds after peripheral stimulation. The general form of the response was consistent among subjects, different deflections having different distributions. Their components 1 and 2 were confined to the contralateral post-quadrant of the head from the post-Rolandic area back to the occiput with the focus of the activity posterior to the surface marking of the Rolandic sulcus. The distributions of components 1, 2, and 3 agreed with Dawson's[18] work in 1950 when he found a response maximum over the surface marking of the Rolandic sulcus but noted that the antero-posterior gradients were asymmetrical around the maximum. Goff et al [31] considered the focus of activity to be posterior to the surface marking of the Rolandic sulcus. Giblin's[27] initial negative potential has a relatively wide distribution and was recorded with much the same amplitude

and latency by electrodes placed anywhere over the contralateral hemisphere behind the central fissure and with a diminishing amplitude for about 3 centimetres in front of it. The early positive potential was slightly more localised over the scalp than the initial negative potential, largest in amplitude when recorded by an electrode in the standard position, ie. over the "hand" area of the post central gyrus. It decreased fairly abruptly when recorded by electrodes in front of the central fissure and decreased more gradually in records from electrodes either medial or lateral to the standard electrode in the same cortical plane. In all these locations it had the same latency but with electrodes three centimetres behind the standard, its peak was both smaller in amplitude and two milliseconds later. The responses evoked in the right and left hemispheres by shocks to the contralateral median nerves were compared in ten subjects. In 8, the early components of responses recorded from the two hemispheres were virtually indistinguishable. Responses evoked by stimulation of the medial or lateral popiteal nerves were largest in amplitude when recorded by scalp electrodes placed approximately over the upper end of the post central gyrus either on the midline or a few centimetres lateral to it. These responses never showed an initial negative component but consisted of a single early positive potential followed by negative and positives waves. S. J. Larson[43] reported that, for each individual, the

latency was not affected by changes in stimulus parameters but the amplitude and configuration of the evoked potential waveform were affected by the position of the recording electrodes and the distance between them. It was apparent that the responses of greatest amplitude were obtained from the electrodes in the vicinity of sensory and motor cortex on the side contralateral to the stimulus. The amplitudes of the potentials evoked by contralateral median nerve stimulation were not bilaterally symmetrical. The amplitudes were greater on the left side in 15 patients and on the right side in 4 patients, and were equal bilaterally in 1. In most of the subjects the amplitude difference was approximately 20 - 25%.

The initial specific response was abolished by concentration and unaltered at rates of stimulation up to 5 seconds. This was reported by L-E Larson[42] in 1953. The primary waves remained unaltered at stimulus rates up to 20 per second but this was tested by Larson only in one case. Dawson[21] reported that the later phase of the evoked potential varied more than the initial response with changes of attention or wakefulness. Giblin[27] showed that the cerebral response evoked by shocks to the median nerve at the wrist or elbow was greatly decreased in amplitude, if, during the time that they were being applied, various kinds of natural stimuli were repeatedly applied to the distal parts of the limb innervated by the same nerve. Repeatedly stroking the skin of the palm or fingers, intermittent pressure on the fingernails, and either passive or voluntary movements of the fingers were all

equally effective. While all components of the evoked response showed a reduction in amplitude roughly in proportion to the intensity of the natural stimulation, the initial negative potential was much less affected than either the early positive or late waves. In most subjects, when shocks of a constant voltage were regularly applied, the amplitude of the evoked cerebral response was observed to decrease with time. The shocks which just exceeded the threshold of some of the motor fibres in the nerve were applied uninterruptedly for 30 minutes. At two minute intervals, the response to 20 consecutive stimuli was averaged. The peak to peak amplitude of the initial negative and positive potentials changed during the experiment. By contrast, the late negative wave of the peak at 42 milliseconds showed an initial increase followed by an abrupt decrease in amplitude. It was likely that the initial increase in amplitude was due to a decrease in resistance to the skin and the stimulating cathode. The sensory and motor thresholds were frequently noted to decrease shortly after the beginning of an experiment and the skin was often noted to become reddened in this area. The decrease in the amplitude of the negative wave after 6 minutes of stimulation did not seem to be due to any subsequent decrease in the effectiveness of the stimulus, since it was not accompanied by any change in the motor response. In other subjects the afferent volley was also monitored and this also did not decrease with time as did the cerebral response. A decrease in the amplitude of evoked potentials

was also observed by Giblin[27], during sleep. The initial negative potential was but slightly reduced whereas the early positive was reduced. Once muscle contractions in response to the stimulus were observed further increases in intensity or duration did not affect the amplitude or configuration of Larson's (S.J.)[43] evoked potential. Increasing the stimulus frequency from 0.5 through 10 cycles per second produced slight reduction of amplitude without change in latency or major alteration of wave form. Although the waveforms were altered by anaesthetic agents, additional changes were not observed during paralysis. When Larson, S.J.[43] produced evoked potentials by stimulation of the dorsal columns during spino-thalamic tractotomy, the recordings obtained with the subject under nitrous oxide anaesthesia with succinlycholine immobilization appeared similar to those obtained with peripheral stimulation of unanaesthetized subjects with normal muscle function. Uttal and Cook[61] reported that the most significant difference between subjects detected during pilot studies was the fact that with certain subjects the M and N waves seemed to be partly or even wholly fused. Deliberate variations in electrode location did not substantially change the waveform. The latency of the M wave was fairly stable varying by only ± 1 millisecond for constant stimulus amplitude. The N wave, however, exhibited more jitter in the averaged responses, displaying recorded ranges as great as ± 4 milliseconds. The O wave variability was very large. The O wave seemed to be related to extremely complex

phenomenon such as awareness, attentiveness, and thought, as one would expect from a process associated with the alpha rhythm. They showed that the preceding stimulus had an inhibitory effect upon the succeeding evoked potential and that this lasted up to 200 milliseconds, and that the M wave was less seriously affected than the N wave. Strong interactions occurred when both the masking and test stimuli were presented to the same side of the body and there was little indication of interaction when they were presented to opposite sides of the body. When the subject was asleep a surprisingly small change occurred in the contralaterally generated M and N waveforms for it was only in the trailing edge of the N wave that any change could be detected. In ipsilateral records the O wave decreased in amplitude as the subject fell asleep. A comparison with the contralateral evoked potential confirmed this was also happening on the contralateral side of the body. There was no significant interaction between responses produced by independent stimuli applied simultaneously to each hand. In 1968, Nezlina and Vorob'eva[53] showed that evoked potentials in the sensorimotor cortex of different cats show individual differences which persist for a long period, that the differences in configuration of evoked potentials were independent of recording conditions (thickness of bone, position of electrode,etc.) and also strength of electrical stimulation of the skin, and that individual differences in evoked potentials probably reflected individual peculiarities in structural and functional organization

of the CNS of particular animals, especially of the cerebral cortex. During polygraphic investigation of monosynaptic reflexes in newborns and on infants, EEG deflections resembling evoked responses and time locked to the tapping of a tendon or muscle, were seen by Hrbek et al[37,38]. The responses, most clearly seen in the contralateral Rolandic area, consisted of a primary and an unspecific component. Latencies became progressively shorter during the neonatal period. The responses were dependent upon the behavioural state. In regular (NREM) sleep the unspecific component was larger. In irregular (REM) sleep it became smaller and the primary component achieved greater prominence. During quiet wakefulness the responses were similar to those in irregular sleep. It was suggested that these responses were probably of proprioceptive origin.

When a conditioning evoked response is followed after an interval by a test response the former will alter the latter. Relative test response amplitude plotted against interstimulus interval yields the recovery function. Recovery is expressed as the ratio of amplitude of test response to that of control response. At the briefest interval between the two stimuli, 3 milliseconds, the average amplitude of Allison's[4] component 1 was more than 60% of the control value. Minimum responsiveness occurred in different subjects at intervals from 5 to 20 milliseconds. Component 1 was approximately 90% recovered in 200 milliseconds. Latency measures obtained for the negative and positive phase of 1 showed little if any change in peak latency as a function of recovery. Several

characteristics of component 5 indicated that it was equivalent to the response previously named "vertex potential" of a "non-specific" nature. It may be evoked by auditory, somatic or visual stimuli. Schwartz and Shagass[59] showed a peak of recovery before 20 milliseconds followed by a decreased responsiveness and a subsequent return to full recovery at 100-200 milliseconds. They also reported decreased recovery with increased intensity.

Dawson[18] in 1950 suggested that the cerebral responses which may be detected in healthy man after electrical stimulation of nerve were probably produced by excitation of at least two kinds of nerve fibre. One type of fibre was that which carried afferent impulses from cutaneous receptors and the other was probably that carrying impulses from proprioceptors in muscle. Records made through skin by Dawson and Scott[22] showed that 70% of the nerve action potential which could be detected was due to activity in fibres with a lower threshold than motor fibres. It was suggested that the volley in these low threshold afferent fibres produced the greater part of the cerebral response. Records of nerve action potentials also indicated that variation in the size of the afferent volley was not the cause of the variation in size of the cerebral responses to successive stimuli of the same kind. Evidence was produced by Dawson[21] in 1956 which suggested that the afferent fibres from the fingers in man were as large as the largest motor or muscle afferent fibres from the small muscles of the hand and that the more excitable fibres from the fingers had an electrical

threshold at the wrist as low as that of the most excitable motor fibres at the same level in the nerve and lower than that of most of the motor fibres. He showed that the cerebral responses may be evoked by stimulation of fibres with a threshold lower than that of the motor fibres and that there was no evidence for the existence of any considerable number of afferent fibres with a threshold lower than that of those giving rise to a cerebral response. No cerebral responses were detected with stimuli just too small to produce paraesthesiae in the fingers, but stimuli which could just be felt produced detectable cerebral responses in some subjects. "If lower thresholds to electrical stimulation and higher conduction velocity can be accepted in any one species as being associated with larger fibres then conditions such as pressure and ischaemia which affect larger fibres first may be expected to affect sensory fibres from the fingers before they affect motor fibres to the hand." (Dawson, 1956[18]). Giblin's[27] initial negative potential at 14 to 18 milliseconds was evoked by relatively weak shocks and as the intensity of the stimulus was increased it reached a maximal amplitude, without decreasing in latency, slightly before the later components of the response. Increasing the intensity of the stimuli seldom decreased the latency of his early positive potential by more than 1 or 2 milliseconds, and a maximal amplitude was obtained in most subjects when the shocks evoked a barely visible motor response. Giblin pointed out that a close correlation was found in all healthy subjects between

the sensory threshold to electrical stimulation and the intensity of stimulus which evoked recordable cerebral potentials. At the sensory threshold (method of limits) subjects reported regularly applied shocks only intermittently. Detectable cerebral potentials were evoked by shocks of this intensity in some subjects but slightly stronger shocks, which just consistently evoked paraesthesiae in the peripheral distribution of the nerve being stimulated, evoked a recordable cerebral response in all subjects - either initial negative and positive potentials of small amplitude or the late positive wave with a peak latency of 40-60 milliseconds. Stronger shocks were required in order that an afferent volley be recordable from surface electrodes placed over the nerve trunk proximally. At the motor threshold the early components of the cerebral response were close to maximal in amplitude, and the afferent volley was usually between 50% and 75% of its maximum. By contrast to the median and ulnar nerves, the thresholds to electrical stimulation of motor fibres in the medial and lateral popliteal nerves were about the same as those of the afferent fibres responsible for the cerebral evoked response. Consistent with this, when stimulating the popliteal nerves, the sensory and motor thresholds were approximately equal. "If it is assumed that for each of the responses after stimulation at phalanges, wrist and elbow the central delay is the same, the difference in their latencies may be used to estimate the rate at which impulses, giving rise to evoked