American Clinical Neurophysiology Society

Guideline 9D: Guidelines on Short-Latency Somatosensory Evoked Potentials[1]

STANDARDS FOR SHORT LATENCY SOMATOSENSORY EVOKED POTENTIALS

I. Introduction

These standards address the recommended methods for recording short latency SSEPs for the purpose of clinical interpretation. The scope of the present recommendation is limited to SSEPs following median nerve stimulation at the wrist for the upper extremity, and posterior tibial nerve stimulation at the ankle for the lower extremity. Considerations common to performance of both upper and lower extremities are discussed jointly in Section II. Individual discussion of upper and lower extremity SSEPs then follows in Sections III and IV.

II. Considerations Common to Upper and Lower Extremity SSEPs

Stimulation

Peripheral nerves are usually stimulated transcutaneously using electrodes placed on the skin over the selected nerve. To minimize discomfort, contact impedance of 5 KOhms or less is recommended. A ground electrode is placed on the stimulated limb to reduce stimulus artifact. Monophasic rectangular pulses are delivered using either a constant voltage or a constant current stimulator. Typical stimulus parameters include a pulse width of 100-300 usec and a stimulation rate of 3-5 Hz. A stimulus intensity adequate to produce a consistent but adequately tolerated muscle twitch is sufficient for standard clinical testing, in which interpretive criteria are based on the presence of requisite waveforms and interpeak latencies. More precise specification of stimulation intensity, for example relative to motor and sensory thresholds, may be desirable for applications in which quantitative SSEP waveform amplitude data are evaluated (Tsuji et al., 1984).

Recording

Standard EEG disk electrodes are used for recording. Contact impedance should be maintained at less than 5 KOhms. Many laboratories find that electrodes applied with collodion are more reliable than those applied with EEG paste.

Most laboratories utilize a system passband of approximately 30-3,000 Hz (—6 dB/octave). Use of a wider passband, extending down to 1 Hz, for example, may have certain advantages for recording long duration signals (Mauguière et al., 1983*a*). This introduces additional low-frequency noise that requires averaging of a greater number of responses and may substantially prolong recording time. More restrictive passbands have been used to examine selected SSEP components (Lueders et al., 1983*b*; Maccabee et al., 1983; Eisen et al., 1984; Yamada et al., 1988). When recording with restricted passbands, linear phase shift digital filtering should be

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used to avoid distortions produced by analog filters (Green et al., 1986). Since the recording passband can significantly affect both the morphology and peak latency of SSEP waveforms, it is essential that testing be performed with the same passband used to acquire normative data.

The analysis time should be appropriate for the SSEP being recorded, for example 40 ms for median nerve SSEPs and 60 ms for posterior tibial nerve SSEPs. It is occasionally necessary to extend the analysis time in order to distinguish between a very delayed and absent response.

The number of responses to be averaged depends on the noise present and the voltage of the signal to be recorded; it ranges from several hundred to several thousand responses. Replication of SSEP recordings to ensure that the recorded waveforms represent stimulus-locked signals and not noise, is mandatory. For low noise recording, two replications are usually adequate. For higher noise recordings, more than two replications are often required.

The most troublesome sources of noise in EP recording are usually muscle activity and patient movement. For this reason, it was historically useful to sedate patients for SSEP recordings. Without sedation, it is often not possible to obtain technically satisfactory studies, particularly using noncephalic reference derivations. Current restrictions on the administration of sedatives in many facilities increase the value of other techniques for obtaining patient relaxation. Because the peak latencies of N20 and P37 cortical responses to median and posterior tibial nerve stimulation can be influenced by the level of subject arousal, it is important that similar conditions be employed for both normative data acquisition and patient testing (Emerson et al., 1988; Yamada et al., 1988; Sgro et al., 1988).

As detailed below, a minimum of four channels are required to record SSEPs. Use of averagers with less than four channels is discouraged.

Designation of Electrode Locations

In this text, Cc and Ci correspond to C3 or C4 positions of the International 10-20 System, respectively contralateral and ipsilateral to the stimulated limb. Similarly, CPc and CPi correspond to positions halfway between C3 or C4 and P3 or P4. CPz is midway between Cz and Pz. C2S and C5S denote electrode positions over the second and fifth cervical vertebrae. Tl0S, T12S, and L2S refer to electrodes over the corresponding thoracic and lumbar vertebrae. EPi corresponds to an electrode over Erb's point, ipsilateral to the stimulated limb. AC refers to an anterior cervical electrode position just above the thyroid cartilage in the midline. LN refers to a lateral neck electrode position at the midpoint of a line drawn between C55 and AC. IC corresponds to an electrode position on the iliac crest. Pfd and Pfp refer to electrodes in the midline of the popliteal fossa, 2 cm and *5* cm respectively above the popliteal crease. REF denotes a noncephalic reference.

Terminology

The system of nomenclature for SSEP waveforms uses N or P to designate the presumed polarity of the recorded signal (negative or positive), and an integer to denote the nominal poststimulus latency of the signal in normal adults. The reader is cautioned that these designations are used inconsistently in the literature. The principal source of ambiguity is the failure of this system of nomenclature to encode recording montage along with polarity and nominal peak latency. For example, one author may speak of an 'N19" recorded from

contralateral scalp to noncephalic derivation, while another may use the same term to designate an entirely different signal recorded on a bipolar scalp to scalp derivation. Ambiguity can only be avoided by specifying the recording derivation in the clinical report.

III. Upper Extremity SSEPs

Designation of Components

SSEPs following median nerve stimulation include the following obligate components.

EP. EP is the propagated volley passing under Erb's point.

N13. Nl3 is the stationary (nonpropagated) cervical potential recorded referentially from the dorsal neck, probably reflecting mainly postsynaptic activity in the cervical cord (Desmedt and Cheron, 198l*a*; Lueders et al., 1983*b*; Emerson et al., 1984).

P14. P14 is a subcortically generated far-field potential, recorded referentially from scalp electrodes. It has a widespread scalp distribution and probably reflects activity in the caudal medial lemniscus (Desmedt and Cheron, 1980, 1981*b*; Mauguière and Courjon, 1981; Emerson et al., 1984).

N18. N18 is a subcortically generated far-field potential, best recorded referentially from scalp electrodes ipsilateral to the stimulated nerve, away from the contralateral N20. It probably reflects postsynaptic activity from multiple generator sources in brainstem and perhaps thalamus (Desmedt and Cheron, 1980, 1981*b*; Tomberg et al., 1991).

N20. N20 reflects activation of the primary cortical somatosensory receiving area (Allison and Hume, 1981; Allison et al., 1980; Desmedt and Cheron, 1981*b*; Hume and Cant. 1978; Mauguière et al., 1983*a,b*; Lueders et al., 1983*a*). N20 is recorded using a bipolar derivation to subtract the widespread far-field signals (e.g., P14 and N18) from the superimposed primary cortical activity recorded locally over the centroparietal region contralateral to the stimulated median nerve (Desmedt and Cheron, 1981*b*).

Stimulation

Median nerve stimulation at the wrist is recommended for standard testing to evaluate the integrity of central somatosensory pathways subserving the upper extremity. The cathode is placed between the tendons of the palmaris longus and flexor carpi radialis muscles, approximately 2 cm proximal to the wrist crease. The anode is then placed 2—3 cm distal to the cathode, or on the dorsum of the wrist. A ground electrode (metal plate electrode, circumferential band electrode, or "stick-on" electrocardiographic-type electrode) is placed on the forearm. Stimulation should produce a clearly visible muscle twitch causing abduction of the thumb.

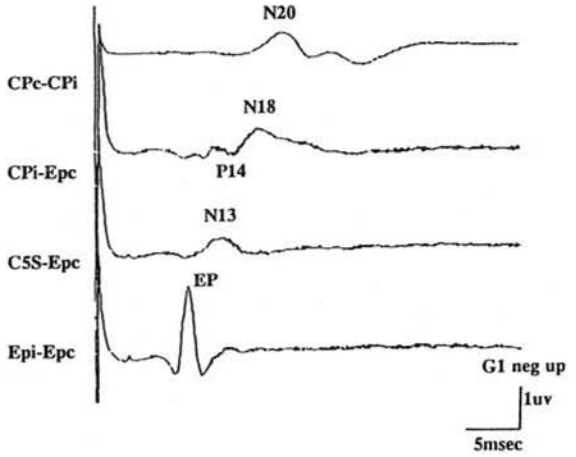

FIG. 10. Channels numbered from bottom to top. Erb's point contralateral to the stimulated limb (Epc) is a recommended noncephalic reference. More distant references, such as elbow, hand, knee, or ankle (bony prominences may also be used).

Recording

Minimal recommended montage. Montage 1, below, is recommended as a minimal montage required to record the obligate waveforms listed below (Fig. 10). It is recognized that alternative montages are also effective in resolving SSEP components listed above (see, for example, Yamada et al., 1986). In the montage listed below, the channels are numbered from bottom to top.

Channel 4: CPc-CPi
Channel 3: CPi-REF
Channel 2: C5S-REF
Channel 1: EPi-REF

Channel 1 of Montage 1 registers passage of the afferent volley past Erb's point (EP). Channel 2 records principally the stationary cervical potential. Channel 3 registers subcortical far-field potentials including P14 and N18. Channel 4 records N20.

Many laboratories presently employ a bipolar C5S-Fpz derivation rather than recording from both C5S and Fpz referentially. The C5S-Fpz derivation confounds temporally coincident signals that are of distinct neural origin and can be differentially affected by neurologic lesions (Mauguière and Ibanez, 1985; Emerson and Pedley, 1986; Urasaki et al., 1988). Specifically, it combines into a single composite waveform, near-field potentials generated in the cervical spinal cord (N13), recorded from the C5S electrode, with more rostrally generated far-field potentials, recorded from the broad region of scalp including the Fpz location (P14, N18). It is recommended that these signals be recorded separately using noncephalic referential derivations (Channels 2 and 3, Montage 1).

Channel 4 records N20 by subtracting the far-field components (P14, N18), registered at CPi (input terminal 2 for the differential amplifier), from a composite of N20 plus underlying far-

field potential, registered at CPc (input terminal 1) (Desmedt, 1981*b*). Figure 11 illustrates derivation of the N20 waveform by subtracting the signal recorded at C4 from that recorded at C3, following left median nerve stimulation.

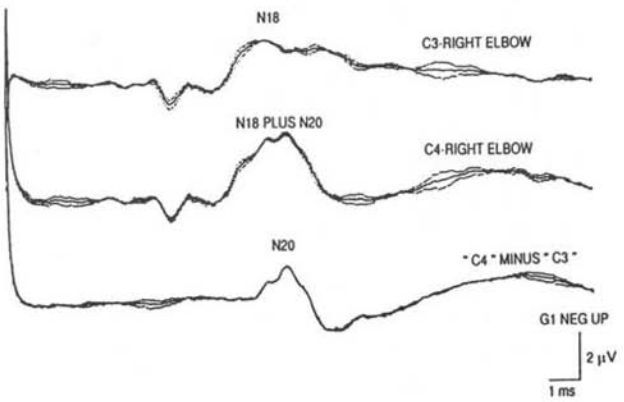

FIG.11. See text for discussion

Many laboratories record N20 using a CPc-Fz derivation. The latter derivation results in a waveform that is a composite of the parietal N20 and the frontal P22. Like N13 and P14, N20 and P22 are generated at a similar time but by different neural structures and are affected independently by clinical lesions (Desmedt and Bourget, 1985; Desmedt et al., 1986, 1987; Mauguière, 1987; Mauguière et al., 1983*b*). The recommended CPc-CPi derivation records N20 in isolation. If desired, a separate channel could be used to record P22 in isolation (see later discussion).

Montage modifications and extensions. Use of a bipolar C5S-Fpz derivation may be helpful in cases in which the amount of noise present in the recording precludes noncephalic referential recording. This derivation exploits the increased signal-to-noise ratio derived from the combination of phase-opposite, approximately simultaneous signals from C5S and Fpz, as well as the elimination of a potentially noisy noncephalic reference. Separate normative data for the composite waveform recorded in this derivation are, of course, necessary.

If additional recording channels are available, the following enhancements to the recording montage are suggested.

1. Additional bipolar scalp derivations permit compensation for normal variations in location of the maximal N20 response (Legatt et al., 1987).
2. A channel may be devoted to recording the frontal P22. Fc (i.e., F3 or F4 opposite the stimulated limb)—CPi records the P22 in isolation in the same manner as CPc-CPi records N20.
3. One or several referential derivations aid in identifying the stationary cervical potential (N13). An additional posterior cervical electrode, e.g., at C2S, provides redundancy for recording this relatively noise-susceptible signal. An anterior cervical electrode (AC), positioned just above the thyroid cartilage registers a positivity (P13) synchronous with the N13, aiding in its identification. Additionally, a bipolar C5S-AC derivation may be used to take advantage of the out-of-phase addition of N13 and P13 signals (Emerson et al., 1984; Emerson and Pedley. 1986; Ursaki et al., 1988).
4. A lateral neck electrode ipsilateral to the stimulated limb (LNi) allows identification of the proximal plexus volley in the neck (Emerson et al., 1984), a point closer to the central nervous

system than the traditional Erb's point electrode location.

5. Additional referential scalp channels may be added to provide redundancy for recording these relatively noise-susceptible channels.

Montage 2 is an example of an extended montage for median nerve SSEP recording.

Channel 8: Fc-CPi
Channel 7: Cc-Ci
Channel 6: Cpc-CPi
Channel 5: CPi-REF
Channel 4: C5S-REF
Channel 3: AC-REF
Channel 2: Lni-REF
Channel 1. Epi-REF

Analysis of results. Each of the obligate components of the median SSEP (EP, N13, P14, N18, and N20) are identified.

The following peak and interpeak latencies are measured: (1) EP; (2) P14; (3) N20; (4) EP to N20, approximating the conduction time between the brachial plexus and the primary sensory cortex; (5) EP to P14, approximating the conduction time between the brachial plexus and the lower brainstem; and (6) P14 to N20, approximating the conduction time between the lower brainstem and the cortex.

Additionally, many laboratories calculate inter-side differences for items (4), (5), and (6). Some laboratories also calculate EP—N13 and N13—N20 inter-peak latencies as measures of conduction time between brachial plexus and cervical cord, and cervical cord to cortex.

Criteria for abnormality. **1. Absence of any obligate waveforms**. Absence of an obligate waveform may reflect either dysfunction of the corresponding generator or failure of that structure to receive ascending input. For example, loss of the N20 may reflect either a cortical lesion per se or a subcortical lesion of the ascending somatosensory pathways.

Implicit in this criterion is that the test must be technically adequate to permit recognition of a waveform if it is present. If, for example, a test demonstrates presence of Erb's point and N20 signals at normal latencies, but subcortical and cervical signals N13, P14, and N18 are not identified because referential channels are contaminated by artifact, the test cannot be interpreted as abnormal. Inability to record reproducible tracings represents a technical limitation rather than a patient abnormality.

2. Prolongation of the interpeak latencies. Prolongation of interpeak latencies and interside interpeak latencies beyond 2.5 or 3 standard deviations greater than the mean of an appropriate control population is interpreted as abnormal and reflecting delayed conduction between appropriate structures. A prolongation of the EP-P14 interpeak latency is interpreted as indicating delayed conduction between the brachial plexus and the lower brainstem. Prolongation of the P14-N20 interpeak latency is interpreted as indicating delayed conduction between the lower brainstem and the cortex.

Because absolute latencies are directly influenced by arm length and temperature, they should not be used as a criterion for abnormality.

P14 sometimes appears as multiple inflections prior to N18 rather than a single positive peak. In such cases, there is uncertainty in the determination of the "true" P14 latency and caution is advised, particularly in the interpretation of small interside-interpeak latency "abnormalities."

Since the latency of the N20 cortical response varies slightly with the level of arousal of the patient, normative data should ideally be obtained, and patient testing should ideally be performed controlling for the level of arousal. In the absence of such controls, caution is recommended in the interpretation of interside latency differences, since the state-dependent shift of the N20 latency (and corresponding interpeak latencies) can be large compared with generally accepted norms for interside-interpeak latency difference (Emerson et al., 1988).

The implication of the choice of any given normal limit, the limitations inherent in the use of the standard deviation for comparing results of individual patients to population norms, and possible uses of alternative measures are discussed in the section of this document entitled "Description of Results and Criteria for Clinically Significant Abnormalities."

3. Other criteria for abnormality. The most reliable criteria for clinically significant abnormalities of SSEPs are the absence of obligate waveforms and prolongation of interpeak latencies as described above. It may be possible to extend the sensitivity of SSEP testing by further including abnormalities of waveform amplitude and asymmetry of amplitude. Care must be taken to (1) establish statistical criteria reflecting the nongaussian distribution of SSEP waveform amplitude in normals and (2) control for the effects of stimulus intensity on waveform amplitude. In the absence of accompanying abnormalities of latency, abnormalities of amplitude should be interpreted with caution.

Morphologic peculiarities of waveforms, unaccompanied by latency prolongation, should not be interpreted as abnormalities. Under appropriate circumstances, however, the interpreting physician should feel free to report a test as within defined normal limits but demonstrating atypical features of uncertain clinical significance.

IV. Lower Extremity SSEPs

Designation of Components

SSEPs following posterior tibial nerve stimulation include the following obligate components.

LP. LP is a stationary (nonpropagated) lumbar potential recorded referentially over the dorsal lower thoracic and upper lumbar spines, reflecting mainly postsynaptic activity in the lumbar cord (Seyal and Gabor, 1985; Emerson, 1988).

N34. N34 is a subcortically generated far-field potential. It is recorded referentially from an Fpz electrode and is most likely analogous to N18 following median nerve stimulation (Seyal et al., 1983; Kimura et al., 1986). It probably reflects postsynaptic activity from multiple generator sources in brainstem and perhaps thalamus. N34 is preceded by a small positivity, P31, most likely analogous to P14 to median nerve stimulation.

P37. P37 reflects activation of the primary cortical somatosensory receiving area. It is recorded using bipolar derivations to subtract widespread far-field signals from the superimposed and topographically more restricted primary cortical activity. There is considerable variability in the scalp topographic distribution of the P37 response. It is usually maximal somewhere between midline and centroparietal scalp locations ipsilateral to the stimulated leg. To avoid erroneously reporting P37 as absent, it is necessary to record from both midline and ipsilateral scalp locations.

Stimulation

Posterior tibial nerve stimulation at the ankle is recommended for standard testing evaluating the integrity of central somatosensory pathways sub-serving the lower extremity. Responses to posterior tibial nerve stimulation are subject to less intersubject variability than those to common peroneal nerve stimulation (Pelosi et al., 1988).

With the patient in the supine position, the cathode is placed midway between the medial border of the Achilles tendon and the posterior border of the medial malleolus. The anode is located 3 cm distal to the cathode.

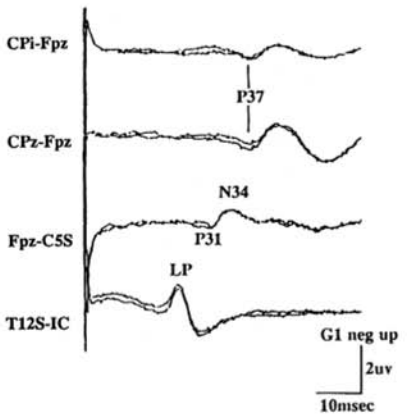

FIG. 12. See text for discussion

Recording

Minimal recommended montage. Optimal recording of lower extremity SSEPs, reliably delineating each of the components listed above as well as recording the afferent volley at the popliteal fossa (helpful in demonstrating adequacy of peripheral stimulation), requires more than the four channels available on most EP recording systems. If a four-channel montage is employed, it is important that the neurophysiologist understands its limitations and recognizes the occasional need to alter the montage.

Montage 1, below, is recommended as a minimal montage to record the obligate waveforms listed above (Fig. 12). It is recognized that alternative montages are also effective in resolving these components (see later discussion).

Channel 4: CPi-Fpz
Channel 3: CPz-Fpz
Channel 2: Fpz-C5S
Channel 1: T12S-REF

Channel 1 records the stationary lumbar potential (LP). LP is widely distributed over lower thoracic and upper lumbar spine and is subject to in-phase cancellation in bipolar spinal derivations. It should therefore be recorded using a referential derivation (Legatt et al., 1986). An electrode on the iliac crest is a convenient reference. Some laboratories prefer to use a midthoracic reference.

Channel 2 records the subcortical far-field P31 and N34 potentials. In contrast to median SSEPs, C5S is relatively inactive following posterior tibial stimulation and hence is a suitable reference for recording subcortical far-field potentials P31 and N34. Other references (shoulder, elbow) may be used, but these offer little advantage and tend to introduce more noise.

Channels 3 and 4 register the P37 primary cortical response. Because of the variability in the scalp topography of this response in normal individuals, P37 may occasionally be present in only one of these channels (Seyal et al., 1983). Use of two channels to record the P37 response is therefore necessary. In channels 3 and 4, Fpz is used as a reference allowing for subtraction of underlying widespread far-field potentials, in a manner analogous to the CPi electrode in channel 4 of montage 1 for median SSEPs (Cruse et al., 1982; Kakigi and Shibasaki, 1983; Lesser et al., 1987; Seyal et al., 1983). Some laboratories use an ear or mastoid electrode rather than an Fpz electrode as an active reference for subtraction of underlying far-field activity.

Montage modifications and extensions. Some laboratories employ a CPi-CPc derivation. This has the potential advantage of improving the signal-to-noise ratio by combining approximately simultaneous phase opposite P37 and N37 signals. It has the potential disadvantage that it produces a combination waveform representing a composite of two somewhat dissimilar signals. If it is employed, the laboratory must have normative data specific to that montage. Additional use of a midline bipolar (CPz-Fpz) derivation is still necessary.

It is often helpful to include a channel devoted to recording the afferent volley at the popliteal fossa. This is particularly useful in cases in which no response is recordable at and rostral to the lumbar spine, making it impossible to distinguish between an absent response and failure to stimulate peripheral nerve. Some laboratories find the use of this channel so often helpful that a Pfd-Pfp derivation is incorporated in their four-channel montage, at the expense of one of the scalp-scalp derivations (channels 3 or 4, montage 3). If this is done, however, it is necessary to repeat any study with an ambiguous or absent P37 response using both CPz-Fpz and CPi-Fpz derivations. Alternatively, other laboratories choose to omit the noise-susceptible Fpz-C5S derivation from routine four-channel recordings in favor of including the popliteal fossa channel.

If additional recording channels are available, the following enhancements to the recording montage are suggested.

1. A channel for recording the afferent volley at the popliteal fossa should be routinely included.
2. Several lumbar channels may be used to delineate the topography of the stationary lumbar potential. It is particularly useful in cases of spinal dysraphism, in which the lumbar potential is often caudally displaced or absent (Emerson, 1988).
3. A CPc-Fpz channel may be added to record the N37 potential, usually present in normals over the parietal scalp contralateral to the stimulated leg. The N37 is a less-consistent feature of the posterior tibial SSEP than P37 and is often of lower voltage.

Montage 2 is an example of an extended montage for posterior tibial SSEP recording:

Channel 8: CPc-Fpz
Channel 7: CPz-Fpz
Channel 6: CPi-Fpz
Channel 5. Fpz-C5S
Channel 4: T10-REF
Channel 3: T12-REF
Channel 2: L2-REF

Channel 1: PFd-PFp

Analysis of results. Each of the obligate components of the posterior tibial nerve SSEP (LP, N34, and P37) are identified. Additionally, the following peak and interpeak latencies are measured: (1) LP; (2) P37; and (3) LP-P37, approximating the conduction time between the lumbar spinal cord and primary sensory cortex.

Some laboratories evaluate LP-P31 and P31-P37 interpeak latencies, approximating conduction time between lumbar spinal cord and brainstem and brainstem and cortex, respectively.

Some laboratories employ correction factors to latency norms adjusting for the patient's height. Height correction is most important when the absolute latency of P37 is evaluated, rather than the LP-P37 interpeak latency. Caution is urged when interpreting uncorrected interpeak latencies for patients whose height is at the extremes of the range of heights for which normative data was collected.

Criteria for abnormality. **1. Absence of any of the obligate waveforms listed above.** Caution regarding technical adequacy, discussed with respect to the median SSEPs applies similarly here. The subcortical N34 potential is a relatively low-amplitude signal, and it may be difficult to resolve in otherwise technically adequate studies in some normal patients. In cases in which the signal-to-noise ratio of the recording is not adequate to detect N34 were it present, failure to record it must not be interpreted as an abnormality. Similar considerations apply for P31 and, in occasional patients, LP.

2. Prolongation of the LP-P37 interpeak latency. Prolongation of the LP-P37 interpeak latency beyond 2.5 or 3 standard deviations greater than the mean of an appropriate control population indicates a delay in conduction between the lumbar cord and somatosensory cortex.

Considerations, discussed with respect to median nerve SSEPs, regarding absolute latency measurements, interside-interpeak latency measurements. and atypical features of uncertain significance apply here as well.

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