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Authors

Pratt, H
Starr, A

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MECHANICALLY AND ELECTRICALLY EVOKED SOMATOSENSORY POTENTIALS IN HUMANS: SCALP AND NECK DISTRIBUTIONS OF SHORT LATENCY COMPONENTS

H. PRATT [1] and A. STARR

Department of Neurology, University of California, Irvine, Calif. (U.S.A.)

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Short latency electrically evoked somatosensory potentials have been described by various investigators, and in some of the studies non-cephalic references were used (Cracco and Cracco 1976; Jones 1977; Kritchevsky and Wiederholt 1978). The surface distribution studies were limited to detailed examination of the short latency components occurring in the nuchal region (e.g., Jones 1977); scalp recording sites were few. The scalp distribution of longer latency components of the somatosensory evoked potentials has been studied (Goff et al. 1977) but the cephalic reference which was used complicates the interpretation of the origin of far-field recorded components.

Recently we have described short latency mechanically evoked potentials (Pratt et al. 1979a) and compared them with electrically evoked somatosensory potentials (Pratt et al. 1979b). In our previous studies both of the electrodes in the differential configuration were cephalic (or nuchal) and thus the distribution of components was difficult to assess because of possible superimposition of constituents in the wave forms recorded.

The purpose of this study was to define the neck and scalp surface distribution of short latency mechanically — as well as electrically — evoked somatosensory potentials in normal humans, using a non-cephalic reference electrode.

Methods

Subjects were 10 adults (5 males and 5 females) 18—38 years old, without neurological disease. They rested on a bed in a sound-attenuating chamber, with their left hand supported on a warmed plastic mold. Digital skin temperature was monitored continuously and maintained between 33 and 36°C. The evoked potentials from each subject were collected in a single session in response to: (1) electrical stimulation of the median nerve at the wrist, and (2) mechanical stimulation of the fingernail. Stimuli were delivered at a rate of 4/sec. Each recording session lasted about 2 h during which subjects were encouraged to sleep.

Electrical stimuli were 0.2 msec duration square pulses of constant current, delivered to the left median nerve through silver cup electrodes, placed at the wrist 3—4 cm apart, over and parallel to the nerve. The proximal electrode was the cathode. Current was adjusted to a level just below that producing a thumb twitch and was never allowed to produce discomfort.

The mechanical stimulus was generated by activating a moving coil vibrator with a 5 msec duration electric pulse. The sound

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[1] Supported by National Institute of Neurological and Communicative Disorders and Stroke Research Fellowship No. IF32NSO6145-01. Present address: Faculty of Medicine, Technion-Israel Institute of Technology, Haifa 32000, Israel. Also to whom reprint requests should be addressed.

produced by the movement of the vibrator was masked by white noise from a speaker near the subject. A more detailed account of the mechanical stimulus has been provided earlier (Pratt et al. 1979a).

Subjects were grounded by a metal plate placed on the left forearm, proximal to the stimulating electrodes. The reference electrode was placed on the right forearm. Silver cup recording electrodes were placed over the 4th thoracic (T_{IV}), the 7th cervical (C_{VII}), the 4th cervical (C_{IV}) and the 2nd cervical (C_{II}) vertebrae, and over the scalp locations of O_z, P_4, P_3, A_2, A_1, C_4, C_z, C_3, F_4, F_3 and F_{pz} according to the International 10-20 system.

The potentials were amplified with a gain of 200,000 using a bandpass of 30—3000 c/sec (3 dB down points, 6 dB/octave slope). The potentials evoked during the 51 msec following the initiation of the stimulus, in response to 1000 stimuli were averaged by an 8-channel averager (using a dwell time of 200 μsec and 256 addresses per channel). The averaged potentials were plotted, with positivity at grid 1 of the differential configuration, i.e. the exploring electrode, as an upward deflection, and stored on magnetic tape for further analysis. A duplicate of each average was made to assess reproducibility. Latencies and amplitudes of components of the potentials were determined from the computer CRT screen with a cursor. Latencies were measured from the onset of the electrical pulse delivered to the peripheral nerves or to the vibrator. Amplitudes were measured between positive or negative peaks and the baseline.

Because the number of recording channels was limited to 8, two sets of recordings were obtained for each method of stimulation. There was always one recording site that was common to both sets. This enabled control of possible changes in the experimental conditions, between the two sets, other than electrode sites.

Data analysis reported here concerns the detection of components and their polarity reversals at the different electrode sites.

Results

The potentials recorded will be described according to the temporal order of appearance of the components at the different recording sites. A summary of the components detected at the different recording sites in response to the two methods of stimulation is presented in Table I.

Electrically evoked potentials

Recordings from two of the subjects presenting typical variations of the potentials are included in Figs. 1 and 2. The initial deviation from baseline was a very minor negativity recorded by all the sites at 6.6 (S.D. = 0.4) msec on the average, followed by a positive deflection, also recorded by all the electrodes, at 9.0 (S.D. = 0.6) msec. These deflections were often not detected at T_{IV} (e.g. subject K.W., Fig. 1). The positive initial component was longer in duration at C_{VII}. At C_{IV} and rostral to it, at all electrode sites, in many of the subjects (7/10), this positivity was biphid with the second peak at 11.8 (S.D. = 0.6) msec (e.g. subject S.W., Fig. 2). The next deviation from baseline was a negativity peaking at 12.2 (S.D. = 0.8) msec at the nuchal electrodes. This component was not recorded at O_z, and was a positivity at 12.6 (S.D. = 0.4) msec at all the electrodes above O_z. Following the nuchal negativity was a positive deviation peaking at 16.8 (S.D. = 1.6) msec which was recorded over the scalp as a prominent negativity peaking at 16.8 (S.D. = 0.8) msec. This negativity was most prominent at the central and parietal electrodes contralateral to the stimulated limb. The descending limb of this prominent negativity often (8/10) had a slight positive inflection at 14.0 (S.D. = 1.0) msec which was best detected on the scalp contralateral to the stimulated limb (e.g. C_4 and P_4 of Fig. 1). At the trough of the scalp negativity there was a positive deflection detected by the frontal electrodes at 19.6 (S.D. = 0.8) msec. The negative peak (21.8 (S.D. = 1.2) msec) following this small frontal positivity

TABLE I

Average latencies and polarities of components of somatosensory potentials evoked by electrical as well as by mechanical stimulation at the recording sites examined. When the positive and negative manifestations of components at different sites did not have the same average latency, both values were listed. P represents a positive component, N stands for a negative one and parentheses denote that the component was not recorded from all subjects. Note the similar surface distributions of corresponding mechanically and electrically evoked components.

Latency (msec)	Electrically evoked											
	Polarity at electrodes											
	Neck	O_z	P_3	P_4	A_1	A_2	C_3	C_z	C_4	F_3	F_4	F_{pz}
6.6	N	N	N	N	N	N	N	N	N	N	N	N
9.0	P	P	P	P	P	P	P	P	P	P	P	P
11.8	(P)	(P)	(P)	(P)	(P)	(P)	(P)	(P)	(P)	(P)	(P)	(P)
12.2, 12.6	N		P	P	P	P	P	P	P	P	P	P
14.0				(P)				(P)	(P)		(P)	(P)
16.8	P	N	N	N	N	N	N	N	N	N	N	N
19.6										P	P	P
21.8				P					P	N	N	N
27.6				(P)					(P)			
30.2								N			N	
31.0				(N)					(N)			
34.6			P				P			P		P
36.4								P			P	
37.8				(P)					(P)			
Latency (msec)	**Mechanically evoked**											
	Polarity at electrodes											
	Neck	O_z	P_3	P_4	A_1	A_2	C_3	C_z	C_4	F_3	F_4	F_{pz}
14.6	P	P	P	P	P	P	P	P	P	P	P	P
18.6, 19.0	N		P	P	P	P	P	P	P	P	P	P
24.0, 23.6	P	N	N	N	N	N	N	N	N	N	N	N
29.8, 29.0				P					P	N	N	N
34.2				(N)					(N)			
34.4							P			P		P
41.2				(P)					(P)			

corresponded in latency to a prominent positive peak (21.8 (S.D. = 2.2) msec) recorded by central and parietal electrodes contralateral to the stimulated limb (C_4 and P_4, Figs. 1 and 2). In some of the subjects (5/10) the descending limb of this positivity, recorded by central and parietal electrodes contralateral to the stimulated limb, had a notch resulting in an additional positive peak at 27.6 (S.D. = 2.4) msec (e.g. subject K.W., Fig. 1). No additional components were detected at the nuchal or ear lobe electrodes. At the central and parietal electrodes ipsilateral to the stimulus and at the frontal region (C_3, P_3, F_3, F_{pz} in Figs. 1 and 2), a slow positivity peaking at 34.6 (S.D. = 2.2) msec was recorded. At the parietal and central regions contralateral to the stimulus (P_4 and C_4, in Figs. 1 and 2), a complex of a negative peak at 31.0 (S.D. = 2.2) msec and a positive peak at 37.8 (S.D. = 2.0)

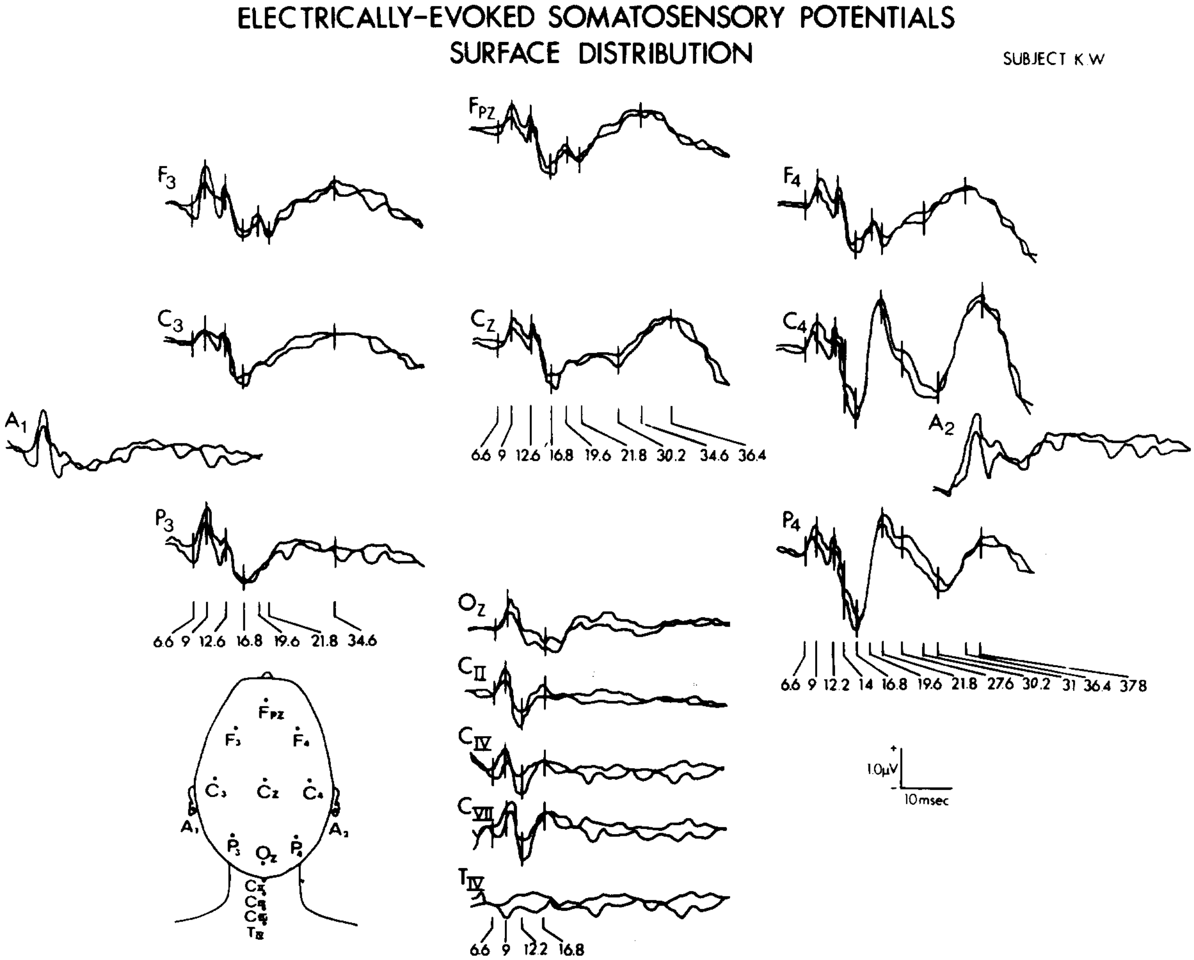

Fig. 1. Potentials recorded in response to electrical stimulation from the electrode sites examined. This subject exhibited some of the variations encountered in our subjects (compare with Fig. 2). The potentials are located approximately according to their surface distribution (see schematic head). Average latencies of the components marked are given in msec.

msec was recorded in some (4/10) subjects (compare Figs. 1 and 2). The vertex and the frontal electrode contralateral to the stimulated limb (C_z and F_4 in Fig. 1) recorded these components with an intermediate morphology between the frontal (F_3, F_{pz}) and the contralateral central and parietal (C_4, P_4) wave forms: a slow positivity peaking (36.4 (S.D. = 2.2) msec) somewhat later than the corresponding frontal positivity (at 34.6 msec), with an ascending limb marked by a negative notch at 30.2 (S.D. = 2.2) msec.

Figs. 1 and 2 demonstrate the variations in the potentials recorded from our subject population. These include the degree of separation of the first two positivities at all recording sites rostral to C_{IV} at 9.0 msec and 11.8 msec, the detectability of the inflection at 14.0 msec on the descending limb of the prominent scalp negativity, the detectability of the 27.6 msec positivity at C_4 and P_4, and the definition of the negative-positive com-

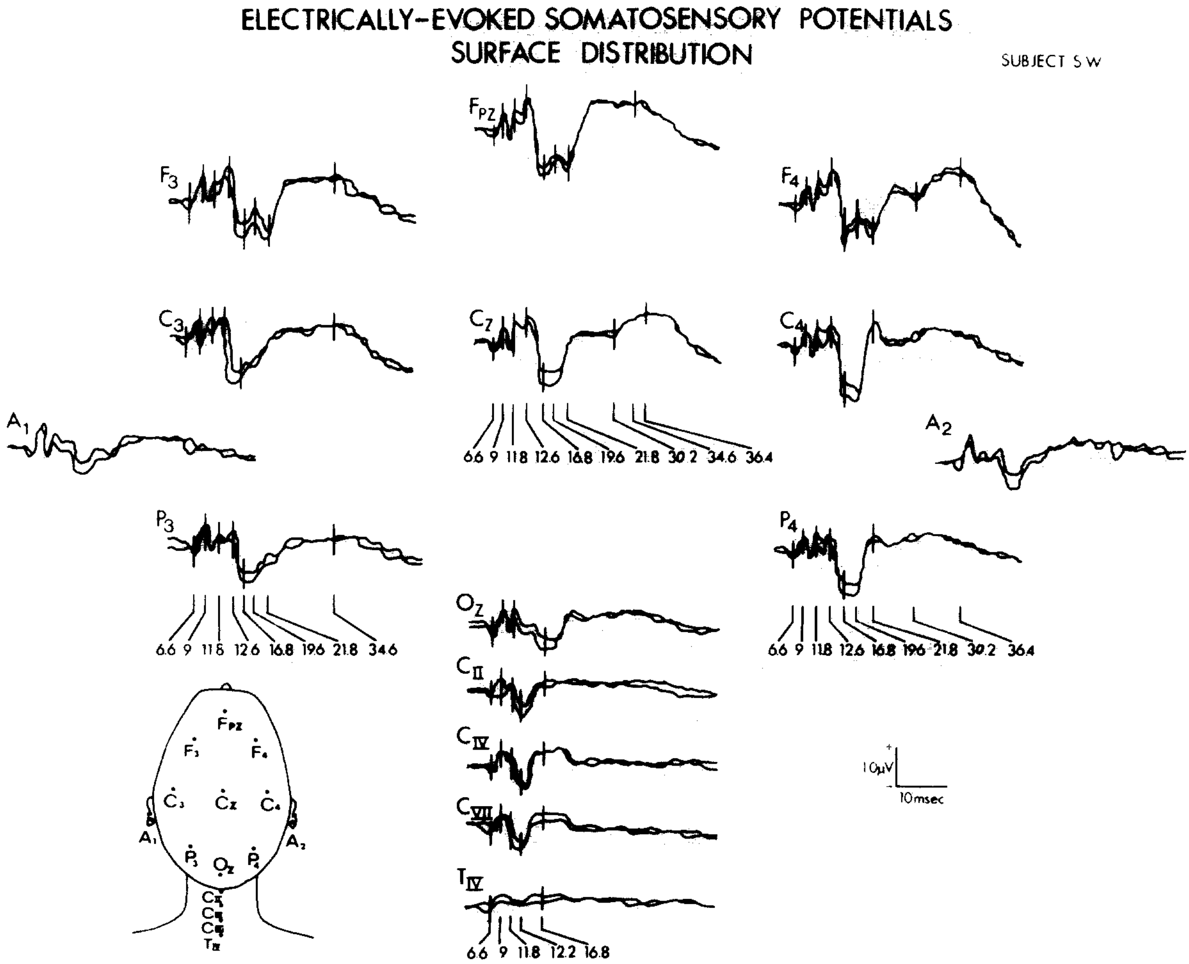

Fig. 2. Potentials recorded in response to electrical stimulation from the electrode sites examined. This subject exhibited some of the variations encountered in our subjects (compare with Fig. 1). The potentials are located approximately according to their surface distribution (see schematic head). Average latencies of the components marked are given in msec.

plex at 31.0—37.8 msec respectively. All other components were very reliably detected in all subjects.

Mechanically evoked potentials

The mechanically evoked potentials recorded from the same subjects of Figs. 1 and 2 are plotted in Figs. 3 and 4 respectively. The mechanically evoked potentials were of smaller amplitude and had fewer components than the electrically evoked potentials.

In most subjects (8/10) the initial deflection was a poorly defined positive peak at 14.6 (S.D. = 0.8) msec at all electrodes. The first clearly discernible deviation from baseline was a nuchal negativity at 18.6 (S.D. = 1.6) msec, which was not detected at O_z, and was positive over the rest of the scalp. Following the nuchal negativity was a nuchal positive peak at 24.0 (S.D. = 2.6) msec which corresponded in latency to a prominent negative peak at O_z and all the electrodes above it (23.6 (S.D. = 2.0) msec). This prominent negativity tends to be double peaked in frontal regions

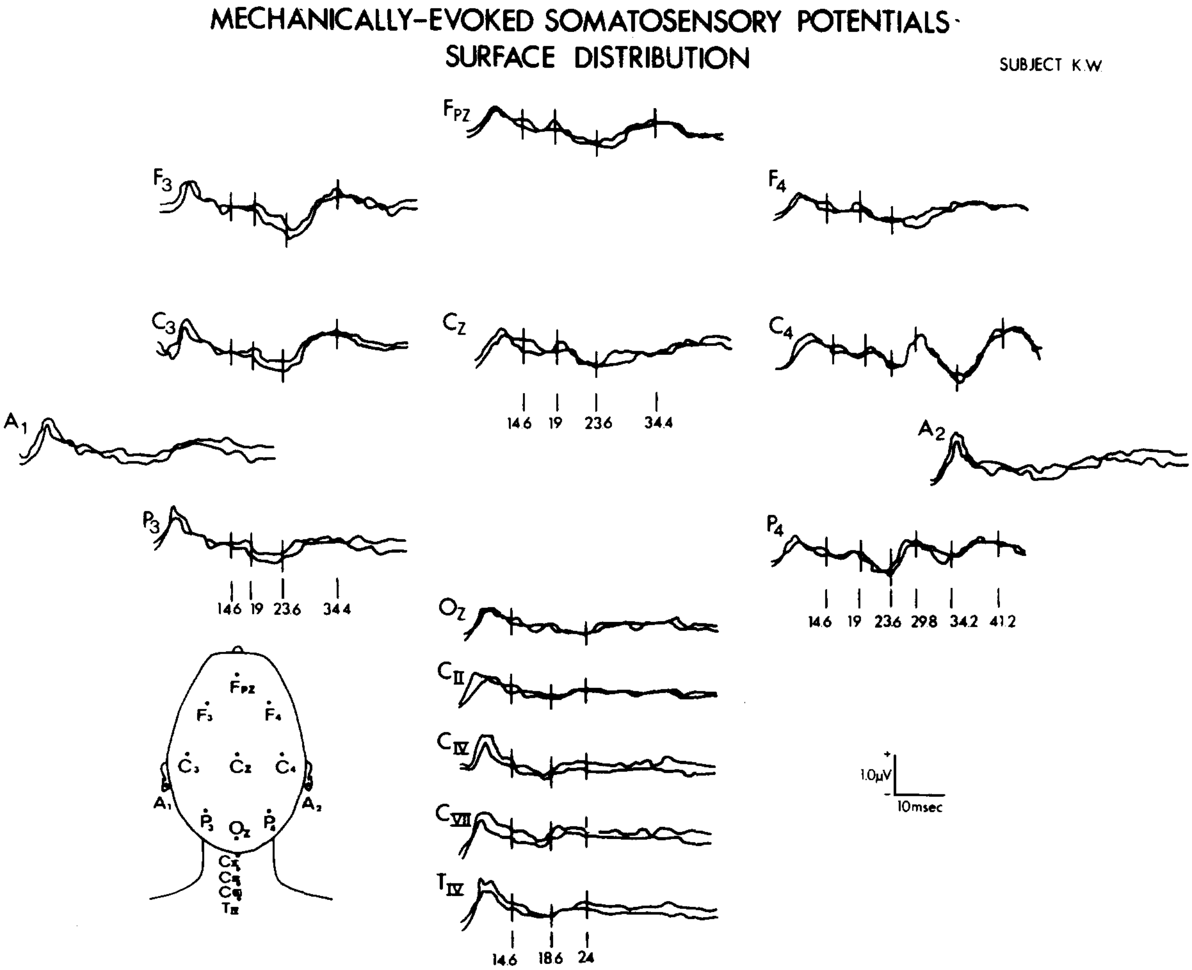

Fig. 3. Potentials recorded in response to mechanical stimulation from the electrode sites examined. This subject is the one whose potentials are included in Fig. 1. Potentials are located approximately according to their surface distribution (see schematic head). Average latencies of the components marked are given in msec.

(e.g. F_3 in Fig. 3) with the latter peak (29.0 (S.D. = 3.5) msec) corresponding to a prominent positive peak (29.8 (S.D. = 2.4) msec) at central and parietal electrodes contralateral to the stimulated limb (C_4 and P_4 in Figs. 3 and 4). From this latency until the end of the analysis period (51 msec) no additional components could be reliably detected at the nuchal and ear lobe electrodes. At the central electrode ipsilateral to the stimulus (C_3), and at frontal electrodes (F_3 and F_{pz}) the next component was a positivity peaking at 34.4 (S.D. = 2.8) msec. In contrast, the parietal and central electrodes contralateral to the stimulated limb (P_4 and C_4) recorded a negative-positive complex with peaks at 34.2 (S.D. = 2.6) msec and 41.2 (S.D. = 2.6) msec respectively. This complex was more pronounced in subjects that produced a comparable complex in response to electrical stimulation (cf. P_4 in Figs. 3 and 4). The vertex and frontal electrodes contralateral to the stimulus (C_z and F_4 in the figures) recorded potentials with an intermediate morphology between that of the frontal (F_3, F_{pz}) and contralateral central and parietal (C_4, P_4) electrodes. The definition of the later

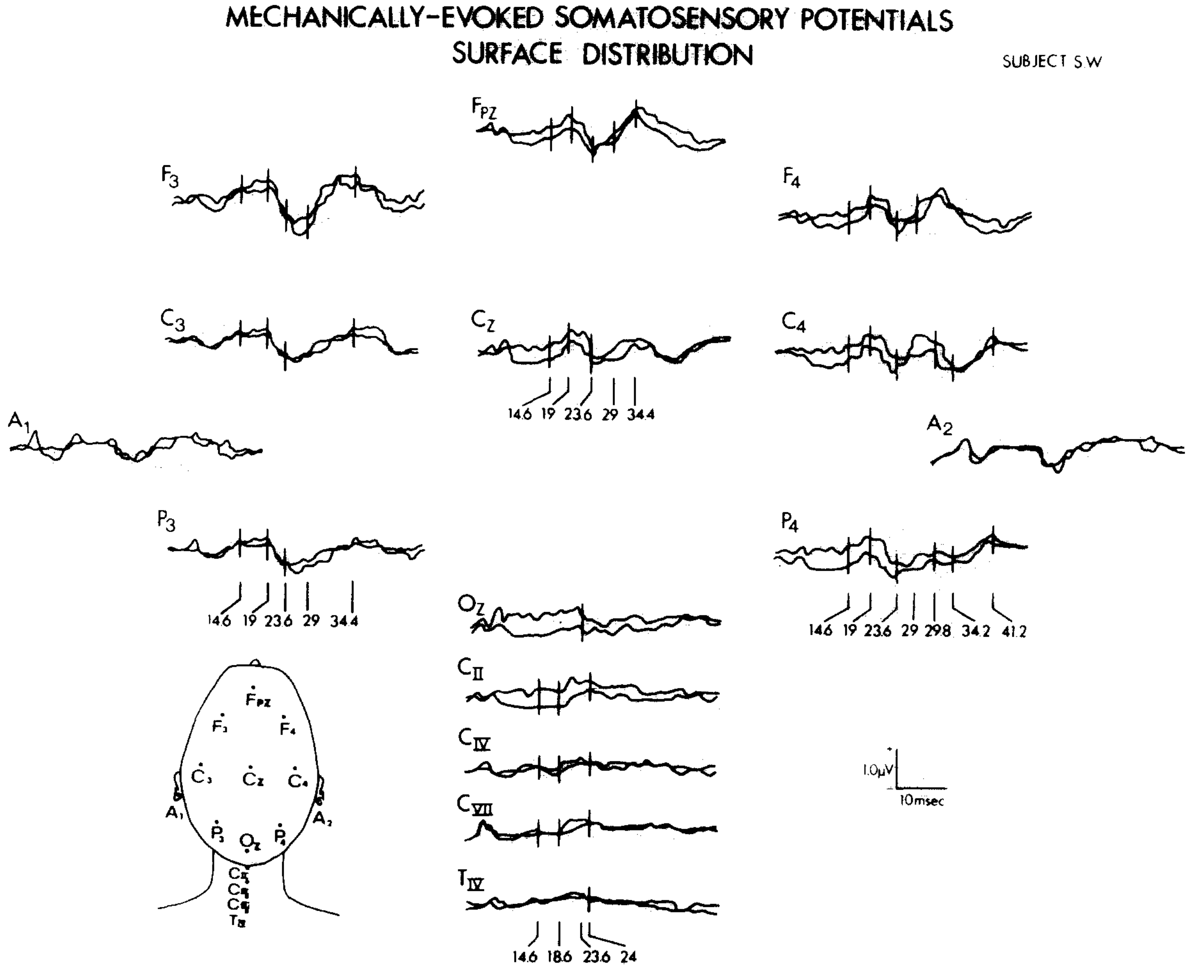

Fig. 4. Potentials recorded in response to mechanical stimulation from the electrode sites examined. This subject is the one whose potentials are included in Fig. 2. Potentials are located approximately according to their surface distribution (see schematic head). Average latencies of the components marked are given in msec.

components at the vertex and contralateral frontal electrodes was variable (compare F_4 and C_z in Figs. 3 and 4).

A summary of all the components detected in response to the two methods of stimulation, at the different electrode sites, is included in Table I.

Discussion

All the components of potentials evoked by mechanical stimulation had electrically evoked counterparts (Table I). Corresponding components of the potentials evoked by the two methods of stimulation had comparable surface distributions and variations within our subject population. The latencies of the comparable components, using the two types of stimuli, differed by about 6 msec, due to the delay introduced in the mechanically evoked potentials by the coupling of the mechanical stimulus to the fingernail and the activation and conduction of neural activity from fingertip to wrist. Some of the electrically evoked components which were of low amplitude and variable in occurrence between subjects did not have mechanically evoked counterparts. The more restricted mechanical stimulus probably failed to activate a sufficient number of neurones to produce such surface recorded components, which even with electrical stimulation were not always detected. An alternative explanation for the larger number of components of electrically evoked potentials is the larger variety of nerve fiber types and neural pathways activated by electrical stimulation of a nerve trunk compared with mechanical stimulation on the receptor surface (Pratt et al. 1979b).

The results of surface distribution studies may suggest possible generators of components assuming a dipole field of the propagated action potential and noting polarity reversal as indicating a generator site. The initial monophasic positive peak (recorded by all the electrodes from all subjects in response to electrical stimuli (9.0 msec) and from some subjects in response to mechanical stimulation (14.6 msec)) is compatible with approaching excitation that never passes any of the electrodes ('killed end' recording). The activity of peripheral nerve and/or brachial plexus is the likely generator for this (Cracco and Cracco 1976; Jones 1977). The second positive peak recorded from some of the subjects, immediately following the initial positivity in response to electrical stimuli (11.8 msec), may be explained as a second recording of nerve activity succeeding the initial one. Such activity could be a delayed peripheral nerve and/or brachial plexus excitation due to slower conduction in smaller diameter nerve fibers. Alternatively this activity may be recorded as a separate peak because of a change in the direction of the propagated action potential in the nuchal region. According to this explanation, the electrode at C_{VII} recorded the activity propagated in both directions from a similar angle, resulting in the broad single peak. This interpretation is in agreement with the earlier suggestion that this second peak derives from a generator at the lower cervical and T_1 roots (Jones 1977).

The nuchal negativity at 12.2 msec to electrical stimulation (18.6 msec to mechanical stimulation) which was not detected at O_z but was recorded as positivity over the rest of the scalp electrodes is consistent with a generator at the upper cervical region or lower brain stem. Using the dipole description, the generator would be a dipole with its positive pole placed rostral close to O_z. Previous results on the effects of varying interstimulus intervals on an analogous component in cats (Wiederholt 1978) and humans (Pratt et al. 1980) suggest this component to be generated postsynaptically, possibly at the dorsal column nuclei. The final nuchal positivity at 16.8 msec to electrical stimulation (24.0 msec to mechanical stimulation), which at O_z and rostral was recorded as negativity and reversed polarity caudal to O_z arises from a different generator than the negative wave recorded over the neck. Both the former's polarity reversal caudal to O_z and the increase in amplitude at the frontal and central electrodes relative to the nuchal recordings suggest a spatially complex generator. The combination of cervical cord repolarization and a diffuse cerebral activity could give rise to such a surface distribution. An alternative explanation, which does not call for superimposition of activities in two separate sites could derive from movement of the generator as the cause of both the polarity reversal and the paradoxically larger amplitude at frontal and central electrodes. Thus, the propagated neural activity generating these components changes direction above C_{II}, at the foramen magnum, and curves toward the floor of the skull between C_{II} and O_z with the positive pole directed dorso-caudally. A likely generator of such activity would be a cuneo-cerebellar tract (Cooke et al. 1971). Depth recordings from animals have shown electrically evoked activity from the inferior cerebellar peduncle at latencies comparable to the analogous component of the cat (Wiederholt 1978). The data to date do not rule out either alternative, and in fact a combination of cuneo-cerebellar, cervical and ascending cerebral activity may be yet another alternative.

The positive inflection on the descending limb of the major scalp negativity at 14.0 msec, to electrical stimulation in some of the subjects, was usually best defined in the scalp locations contralateral to the stimulated limb. This is consistent with ascending activity such as the medial lemniscus and thalamus. The analogous component in the cat was abolished by a high brain stem transection (Iragui-Madoz and Wiederholt 1976). Depth recordings from humans during stereotaxic surgery have shown thalamic activity at this latency range (Larson and Sances 1968; Narabayashi 1968; Matthews et al. 1970), but on the basis of present data it would be premature to locate the generator of this scalp-positive component.

The positive deflection recorded by the frontal electrodes (19.6 msec to electrical stimulation) at the trough of the scalp's major negativity preceded by 2 msec the prominent positive peak recorded from the scalp contralateral to the stimulated limb. This frontally recorded positive component, whose peak corresponded in latency to the prominent negativity at C_4 and P_4, could be generated by a dipole between central and frontal regions contralateral to the stimulated limb, parallel to the surface and with the positive pole pointing frontally. The subsequent positivity localized at the central and parietal electrodes contralateral to the stimulus is compatible with a dipole source located vertical to the somatosensory cortex with positivity at the surface. A dual generator, in the vicinity of the specific somatosensory cortex, having both surface parallel and surface vertical constituents has been suggested based on brain surface mapping during surgery (Allison et al. 1980).

The negative peak at the central and parietal electrodes contralateral to the stimulus and the prolonged positive wave at the other scalp electrodes are compatible with activity spreading away from the specific sensory areas to the other cortical regions. An alternative explanation may be less synchronous activity in S_{II}, on the upper wall of the lateral sulcus, which is inverted relative to S_I in the postcentral gyrus.

A surface distribution study on patients with well localized lesions must be performed in order to support or disprove the possible generators proposed. Such a study would also help in deciding on the clinically most useful electrode configurations for the determination of site and extent of neurological lesions.

Summary

Short latency somatosensory potentials evoked by electrical stimulation of the median nerve as well as by mechanical stimulation on the nail of the index finger were recorded from 10 normal adults using a non-cephalic reference (the forearm contralateral to the stimulus). Potentials were recorded from 15 electrode locations extending from the level of the 4th thoracic through the 7th, 4th and 2nd cervical vertebrae to the scalp at O_z, P_4, P_3, A_2, A_1, C_4, C_z, C_3, F_4, F_3 and F_{pz}. In general, all the components of potentials evoked by mechanical stimulation had electrically evoked counterparts with comparable surface distributions and variations between subjects. Some of the electrically evoked components, which were low in amplitude and variable in occurrence between subjects, did not have mechanically evoked counterparts. Possible generators of the components detected are discussed based on their surface distribution and polarity reversals. A comparable study on patients with well localized lesions must be performed in order to support or disprove the generators proposed.

Résumé

Potentiels somatosensoriels évoqués électriquement et mécaniquement chez l'homme: distributions sur le scalp et le cou des composantes à latence courte

Les potentiels somatosensoriels à courte latence évoqués par la stimulation électrique du nerf médian aussi bien que par stimulation mécanique sur l'ongle de l'index ont été enregistrés chez 10 adultes normaux en utilisant une référence non céphalique (le bras contralatéral à la stimulation).

Les potentiels ont été enregistrés par 15 électrodes réparties ainsi: 4ème vertèbre thoracique, 7ème, 4ème et 2ème cervicales et sur le scalp en O_z, P_4, P_3, A_2, A_1, C_4, C_z, C_3, F_4, F_3 et F_{pz}. En général, toutes les composantes des potentiels évoqués par la stimulation mécanique avaient leur contrepartie dans le potentiel évoqué électrique avec des distributions et des variations de surfaces comparables entre les sujets. Certaines composantes évoquées électriquement, qui étaient d'amplitude faible et d'occurence variable selon les sujets, n'avaient pas leur contrepartie dans le potentiel évoqué mécaniquement. A partir de l'inversion de la polarité et de la distribution de surface des composantes détectées, on discute de possibles générateurs. Une étude comparable sur des patients avec lésions bien localisées doit être faite afin de confirmer ou d'infirmer l'existence des générateurs proposés.

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