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STATIONARY NEGATIVE POTENTIALS NEAR THE SOURCE VS. POSITIVE FAR-FIELD POTENTIALS AT A DISTANCE [1]

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Experimental Section

The concept of far-field potentials has helped to improve our understanding of the neuro-anatomical substrates for brain-stem auditory (Jewett et al. 1971; Starr and Achor 1975; Stockard and Rossiter 1977) and short-latency somatosensory evoked potentials (Cracco and Cracco 1976; Jones 1977; Desmedt and Cheron 1980; Yamada et al. 1980). This type of recording allows detection of a distant potential before the arrival of the signal at the pick-up electrode. Thus the method has become increasingly popular for clinical assessment of a generator source which would otherwise be accessible only by an invasive technique. Far-field potentials represent approaching fields of positivity, occurring in advance of a propagating impulse. This is in contrast to the recording of a primarily negative near-field potential using a bipolar derivation.

In our recent studies, we have shown that stationary potentials are generated when the traveling impulse reaches a boundary between two adjacent conducting media where the current density changes suddenly (Kimura et al. 1983, 1984). However, it is not known why widespread stationary positive potentials are generated when

moving impulses cross the border of volume conductor. Also uncertain is the relationship between the propagating negativity and the far-field positive potential recorded at a distance. In the present study, we will document the presence of additional stationary peaks preceding the P9 potential after stimulation of the median nerve. We will also establish the field distribution of these stationary peaks by recording the potential not only from the stimulated subject but also from a second subject indirectly in contact with the generator source.

Materials and Methods

We studied the field distribution of short-latency somatosensory evoked potentials (SEPs) in 15 healthy volunteers aged 18-43 years (mean of 32 years). The subjects' informed consent was obtained. Recording electrodes were silver-silver chloride cups filled with ECG gel attached to the skin with collodion. Electrode impedance was maintained at 5 kΩ or less. The placement of recording electrodes varied depending on the experiment: usually one electrode was located at C3 or C4 in accordance to the 10-20 system and multiple electrodes over the arm, leg or trunk. A number of electrode derivations were tested and are described in detail later in Results. Stimulus electrodes were flat-surfaced disks which were 7 mm in diameter for stimulation of the median nerve at the wrist and ring electrodes for stimulation of the finger. The cathode was located proximal to the anode. Stimuli with a pulse duration of 0.1 msec were delivered by a stimulator through an isolation unit at a rate of 4-5/sec. The intensity

was adjusted so as to elicit a modest but painless twitch of the abductor pollicis brevis for median nerve stimulation at the wrist. For finger stimulation, the intensity was 3.5 times the sensory threshold.

Recorded potentials were fed to a 16-channel differential amplifier with an amplification of 20×10^3. The AD converter range was ±1 V with a resolution of 10 bits. The frequency response was 10–1000 Hz (3 dB down). Up to 16 channel outputs were summated simultaneously by a 21 MX Hewlett-Packard computer and the responses were plotted by an X-Y plotter. The digitized intersample interval was 0.1 msec with an analysis time of 20 msec. A total of 1000–1500 responses were averaged for each test. Each test was repeated to confirm the reproducibility of the response.

The computer was programmed so as to reject responses with 7 successively overloaded points in order that samples which unrealistically large potentials contaminated by ECG or muscle artifacts were deleted. The averaged responses were stored on a digital tape and displayed on an oscilloscope screen for measurement. The peak amplitude and latency values were indicated on the video monitor by moving the cursor to the point of interest.

Results

(1) Stationary negative peaks recorded at the arm

In our earlier study (Yamada et al. 1980), the negative potential recorded from the acromion on the side of stimulation (N9) was found to coincide with P9 recorded from the scalp with a non-cephalic reference after stimulation of the median nerve at the wrist. This was thought to be a propagating nerve impulse running across the axilla. In this study, however, we found that N9 was distributed widely from the shoulder to the upper arm recorded from multiple electrodes placed over the lateral aspect of the arm with reference at the knee (Fig. 1). Preceding N9, there was an additional negative peak, N6, which was also stationary in latency over a wide area of the stimulated arm. In contrast to the P9-N9 relationship, N6 remained negative as far proximally as the scalp in most subjects (Fig. 1).
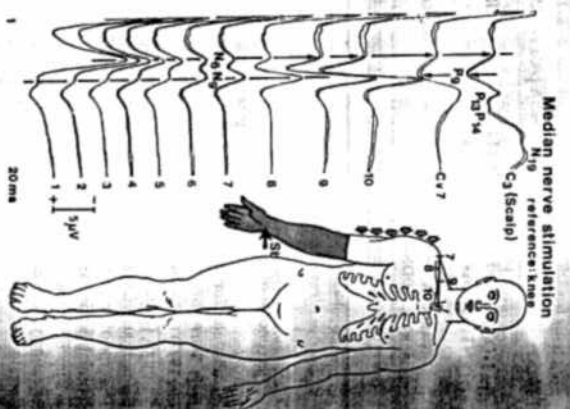
Fig. 1. Potentials recorded from multiple electrodes placed over the lateral aspect of the upper arm to the shoulder with the reference following stimulation of the median nerve at the wrist. N9 peak, corresponding to P9 from the scalp, has a fixed latency from the shoulder up to the distal part of the upper arm. The potential recorded at Erb's point (electrode 9), which reflects a traveling impulse has a slightly longer latency than P9 or N9. Preceding N9, there is an additional stationary peak, N6, which extends from the upper arm to the scalp. In this and subsequent figures, the arm marked by the shade is the stimulated side.

To delineate further the distribution of N6 and N9, recordings were made from multiple electrodes placed in a circle around the arm at different levels, one was at the level of the axilla and the other at the distal end of the deltoid muscle (Fig. 2). N6 latency was fixed irrespective of the recording site except at the axilla where propagating nerve impulses had a slightly longer latency than N6 (A in Fig. 2). The latency of the negative potential was the same as that of the negative potential

recorded at the level of the distal end of the deltoid (A' in Fig. 2). The amplitude of N6 was greatest at this level.

We then compared the peripheral nerve potentials referenced to the knee to those obtained from sequential bipolar derivations. Multiple electrodes were placed along the nerve trunk with equal interelectrode distances as shown in Fig. 3. In referential recordings, multiple peaks were registered especially at the distal part of the forearm. Beside N6 and N9 which were described earlier, there was an additional stationary peak, N3, recorded over the forearm. In contrast to the bipolar recording which effectively canceled the stationary peaks and showed di- or triphasic propagating nerve impulses, the referential recording resulted in an amalgam of stationary and propagating potentials. At a certain electrode position, for example at electrode 4 in Fig. 3, distinct separation between stationary peaks and propagating impulses occurred, with the first one corresponding
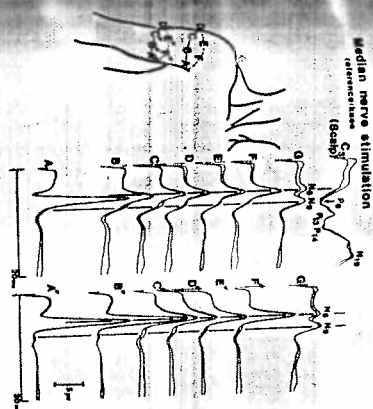
Fig. 2. Potentials recorded from electrodes circumferentially placed at the level of axilla and distal end of the deltoid. Electrodes A and A' were placed over the nerve trunk. N6 latency is fixed regardless of the electrode location except at A where the traveling impulse is registered. At the B electrode the negative peak latency is inbetween N6 and the overlying impulse at electrode A. Also note the fixed latency of N9.

to N3 and the second one likely representing the propagating nerve impulse. At other locations, the potentials had long durations with notched wave configurations which suggest that the stationary nerve impulses. N3 latencies were close to that of the negative peak obtained from the bipolar recording at the distal insertion of the brachioradialis while the latency of N6 matched that of the potential at distal end of the deltoid (Fig. 3).

To prove that these stationary peaks are activated by sensory impulses, we made similar recordings after stimulation of the thumb, middle or little finger (Fig. 4) and found essentially the same features as shown in Fig. 3. The latencies of N3, N6 and N9 were approximately 3 msec longer with stimulation at the finger than at the wrist. This indicates that these potentials are generated at anatomically fixed locations irrespective of the site or kind of nerve stimulated. With finger stimulation, there was an additional stationary peak, P0-N0, recorded as far proximal as the shoulder. This corresponded with the potential generated at the wrist, described recently by Kimura et al. (1983). These stationary peaks were best recorded from the electrodes placed over the lateral aspect of the arm presumably because traveling nerve impulse had little influence over these electrodes (Fig. 5).

These findings suggest that N9 represents a negative near-field potential and P9 the positive far-field counterpart. However, the positive counterpotentials of N3 and N6 were not readily identified. With the recording from multiple electrodes placed over the scalp, trunk and the leg referenced to the great toe, however, we found that there were small but distinct positive-negative peaks registered at the electrodes below the mid-thoracic region (Fig. 6). These potentials were small but consistently identified in 4 subjects tested. The positive phase of these potentials was found to correspond with N6 recorded from the stimulated arm. The findings indicate that there was considerable difference in the field distributions of N6-P6 and N9-P9. The counterfield of positivity for N3 was not found with certainty in part due to technical difficulties caused by stimulus artifacts.

Table 1 shows the latencies of N0, N3, N6 and

Median nerve stimulation at the wrist

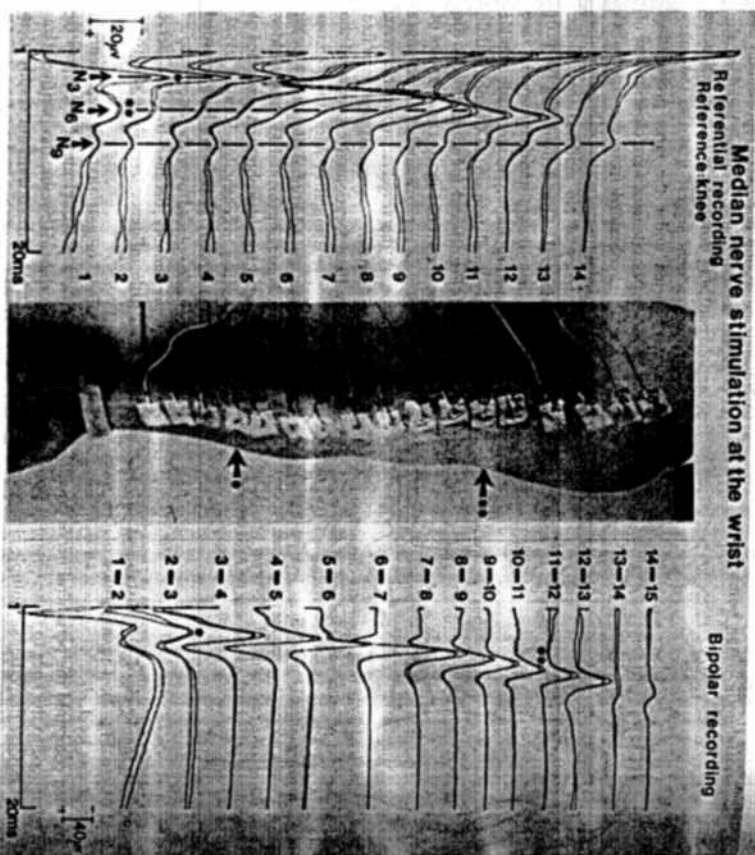Referential recording
Reference:knee

Bipolar recording

Fig. 3. Potentials recorded by referential (left column) and sequential bipolar derivation (right column) from electrodes placed over the nerve trunk. Multiple peaks were recorded with the referential derivation. In addition to N6 and N9, another stationary peak, N3, was recorded at the forearm. The peak latency of N3 and N6 was close to the nerve potential recorded at the distal insertion of the brachioradialis (one star mark) and deltoid (two star marks), respectively, by bipolar derivation. Apparently the bipolar recording effectively canceled these stationary peaks.

N9 recorded at the dorsum of arm where contamination of propagating action potential was minimal after stimulation of the first, third and fifth finger and the median nerve at the wrist, in 15 normal adult subjects. N0 was recorded only after finger stimulation. From the scalp, P9 was

recorded in all subjects and N6 was identified in most subjects.

(II) Transmission of stationary negative and far-field positive potentials to a second and a third person.

Thus far we have shown that N9 and N6 repre-

Middle finger stimulation
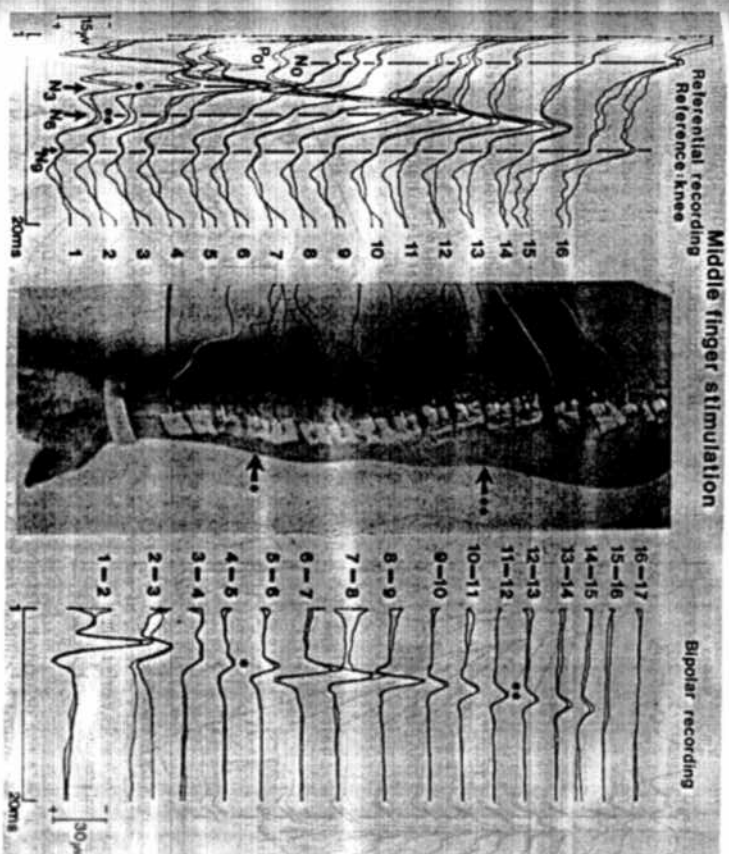
Referential recording
Reference:knee

Bipolar recording

Fig. 4. The same recording setting as Fig. 3, but after stimulation of the middle finger. The stationary peaks, N3, N6 and N9 were recorded, but with a latency about 3 msec longer than with median nerve stimulation at the wrist. The latencies of N3 and N6 matched the nerve potentials recorded with the same anatomical location as with median nerve stimulation. In addition to N3, N6 and N9, there was another stationary peak, P0/N0, which was described earlier by Kimura et al. (1983).

sent stationary negative peaks located close to the generators and that P9 and P6 are their counterfields of positivity at a distance. P9 extended from the scalp, neck, opposite (non-stimulated) arm to the mid-thoracic region, while P6 occupied the lower half of the body. However, this is based on the assumption that the reference electrode placed at the leg is electrically 'indifferent' or on the prerequisite that the found potential fields are relative to the reference activity. It is unlikely that

N3, N6 and N9 recorded from the stimulated arm arise from positivity at the reference electrode because each showed characteristic potential gradients along the longitudinal array of electrodes over the arm. However, this possibility cannot be excluded unless clarified by the use of 'neutral' reference. To solve these problems we made an electrical connection between two persons by touching arms with the idea that the expanded volume of electroconductive medium would pro-

suming that P9 is positive at the shoulder relative to the knee in the stimulated subject, the finding unexpectedly suggest that the entire body of the non-stimulated subject became active for P9 by transmission through the contralateral arm. In a similar way, knee to knee recordings registered well defined P9 potentials. The transmission of P9 from stimulated to non-stimulated subject was further supported by changing the bodily contact to the leg. In this setting, P9 was present at the shoulder of the stimulated subject when referenced

Median nerve stimulation reference: knee

Fig. 5. Potentials recorded from the lateral aspect of arm. This revealed 'pure' stationary peaks, N3, N6 and N9, devoid of contamination from the traveling impulse. Note the differences in potential gradients of these 3 peaks.

vide a less active or neutral reference. The arm contact was secured by applying ample ECG gel over the skin surface and wrapping a wet cloth soaked with saline solution around the arms. Nearly two-thirds of the arm length were thus contacted. If the contact area was small, the recording was technically impossible due to 60 Hz interference.

As is shown in Fig. 7, the contralateral (non-stimulated) arm of the stimulated subject was in contact with the non-stimulated subject. The P9 peak, which was recorded from the shoulder-knee derivation in the stimulated subject, was absent when referenced to the shoulder or to the knee of non-stimulated subject. This can be explained if the shoulder or the knee of the non-stimulated subject has a potential equal to that of the contralateral shoulder of the stimulated subject. As-

Left median nerve stimulation reference: right big toe

Fig. 6. Recording from the scalp trunk and the leg referenced to the big toe after stimulation of the median nerve. There was a small but distinct positive peak (P6) at and below mid-thoracic region. P6 corresponded with N6 recorded from the shoulder of the stimulated arm. Note the differences in potential distribution of P6 and P9.

Median nerve stimulation

Fig. 7. Recording between stimulated and non-stimulated subjects with the contralateral (non-stimulated) arm in contact with the non-stimulated subject. After arm connection, P9, recorded from the shoulder contralateral to the side of stimulation referenced to the knee (2–3) within the stimulated subject, was absent when referenced to the shoulder of the non-stimulated subject. Well defined P9 was recorded from the knee of the non-stimulated subject (5–3). This can be explained by the equipotentiality at electrodes 2, 4 and 5 by transmission of P9 from the stimulated to the non-stimulated subject via arm contact. In contrast, P9 was not registered from the same electrode derivation (5–3) with leg connection only (left column), presumably because P9 was not transmissible through the leg. In the latter connection, P9 was present from the shoulder of stimulated subject referenced to the non-stimulated subject who apparently served near 'neutral' reference.

TABLE I

Latencies (in msec) of N0, N3, N6 and N9 after median nerve and finger stimulation (15 subjects).

( ): latency of corresponding peaks identified from the scalp electrode. They are positive for N9 and negative for N6. N indicates the number of subjects identified.

		N0 (wrist)	N3 (forearm)	N6 (humerus)	N9 (acromion)
Median nerve at wrist		3.36 ± 0.49	6.11 ± 0.68 (6.38 ± 0.81) N = 11	8.57 ± 0.59 (8.69 ± 0.64) N = 15	
Finger	I	2.37 ± 0.86	5.76 ± 0.52	8.20 ± 0.83 (8.36 ± 0.96) N = 10	11.25 ± 0.62 (11.38 ± 0.79) N = 15
	III	3.24 ± 0.34	6.09 ± 0.70	9.09 ± 0.91 (9.18 ± 1.01) N = 10	12.02 ± 0.67 (11.87 ± 0.61) N = 15
	V	2.83 ± 0.48	5.78 ± 0.73	9.31 ± 0.58 (9.30 ± 0.88) N = 9	11.96 ± 0.74 (11.84 ± 0.84) N = 15

to the non-stimulated subject. In contrast to the arm connection, no responses were registered with a knee to knee derivation.

We then tested the mode of transmission to the non-stimulated subject by changing the contact to the stimulated arm (Fig. 8). With stimulation of the finger, P9 and P14 were recorded from a scalp-knee derivation from the stimulated subject. When the reference was changed to the shoulder or knee of the non-stimulated subject, there were 3 additional positive-negative peaks preceding P9. The downward deflections of these peaks corre-

sponded with the N0, N3, N6 and N9 potentials recorded from the stimulated forearm. The absence of the first 3 peaks with the scalp-knee derivation within the stimulated subject may be due to equipotentiality of these peaks between the scalp and knee. However, this possibility is doubtful because of the characteristic potential gradient for N0, N3 and N6 when recorded from the stimulated arm with use of the same knee reference. It is thus likely that N0, N3, N6 and perhaps N9 from the stimulated arm are transmitted to the non-stimulated subject, and surprisingly extended

Index finger stimulation

1–2 · · · P9 P14

1–3 · · · N0 N3 N6 N9 P14

5–2 · · · N0 N3 N6 N9

1–4 · · · P14 + − 2µV

22ms

Fig. 8. Recording between stimulated and non-stimulated subjects with the stimulated arm in contact with non-stimulated subject. The index finger was stimulated. In addition to P9 and P14 peaks normally recorded from the scalp-knee (1–3) derivation from the stimulated subject, there were 3 additional peaks when the reference was changed to the shoulder (1–3) or knee (1–4) of the non-stimulated subject. Downward deflection of these 3 peaks matched N0, N3 and N6 recorded from the forearm of the stimulated subject (5–2). This is explained by the presence of N0, N3 and N6 at the shoulder or knee of the non-stimulated subject transmitted from the stimulated subject by arm contact.
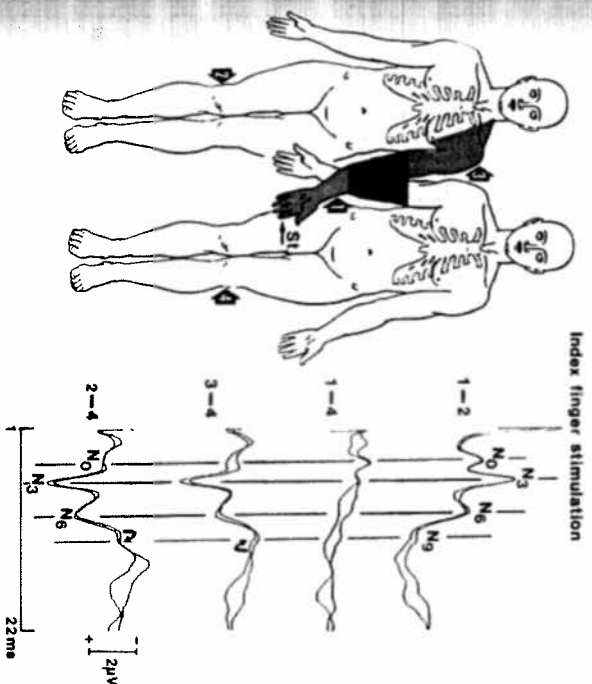
as far as the knee of the non-stimulated subject. Nearly identical responses were obtained with the use of a reference at either the shoulder of the contacted arm or the contralateral knee. This indicates that the transmitted potentials are distributed evenly over the body without decline in amplitude. Indeed, no potentials were recorded with the contacted arm-knee derivation in the non-stimulated subject.

Transmission of N3, N6 and N9 to the non-stimulated subject was further supported by the results shown in Fig. 9. From the electrode placed on the forearm with the use of a knee reference in the stimulated subjects, there were prominent N0,

N3 and N6 peaks, and a small N9. When the reference was changed to the knee of the non-stimulated subjects, these potentials were much smaller presumably due to cancellation between the forearm electrode of the stimulated subject and the knee electrode of the non-stimulated subject. With recordings from the acromion and the knee of the stimulated subject referenced to the knee of the non-stimulated subject, the responses were similar, except that N9 showed upward deflection from the acromion and downward from the knee. This was likely due to the larger negativity at shoulder of the stimulated arm than the transmitted N9 at the knee of the non-stimulated subject.

Index finger stimulation

1–2 · · · N0 N3 N6 N9

1–4 · · ·

3–4 · · ·

2–4 · · · N0 N3 N6

22ms + − 2µV

Fig. 9. The same setting as Fig. 8 in a different subject. N0, N3, N6 and N9 recorded from the forearm of the stimulated subject were small or absent when referenced to the knee (1–4) of the non-stimulated subject presumably due to transmission of N0, N3, N6 and probably N9 to the non-stimulated subject. Recordings from the shoulder (3–4) or knee (2–4) of the stimulated subject referenced to the knee of the non-stimulated subject showed similar potentials except for N9 which was upward at the shoulder (3–4) but downward at the knee (2–4). This can be explained by the larger N9 at the shoulder of the stimulated subject than the N9 transmitted to the non-stimulated subject.

With any electrode derivation no potentials were recorded if both active and reference electrodes were placed on the non-stimulated subject. This suggests that the transmitted potentials are distributed evenly over the entire body. To further prove that N0, N3, N6 and N9 recorded between the stimulated and non-stimulated subjects arise from the non-stimulated subject, 3 subjects were connected by arms while the second subject received the stimulus (Fig. 10). N0, N3, N6 and N9 were recorded from the shoulder of the first subject whose arm was in contact with the stimulated arm, with reference at the shoulder of the third subject whose arm was in contact with the non-stimulated arm. Phase reversal occurred in the recordings from the scalp of the stimulated subject to the

shoulder of the first subject. The findings support the impression that N0, N3, N6 and N9 were transmitted to the non-stimulated subject when the arm was in contact with the stimulated arm.

(III) Transmission of N3, N6, N9 and P9 through the stimulated subject

To investigate if N3, N6, N9 and P9 are transmissible through the body of the stimulated subject, recordings were made from the knee or ankle to the opposite knee: usually no responses are registered in this derivation after stimulation of the median nerve. A 10 cm × 6 cm pad electrode was placed over the upper arm, shoulder or neck. This was connected via a cable with a strap electrode wrapped around the leg just below the knee

Index finger stimulation

Fig. 10. Recordings from 3 connected subjects with the middle (2nd) subject being stimulated. With a 2-subject connection, no potentials were recorded by any derivation if both active and reference electrodes were placed over the non-stimulated subject presumably due to the equipotential distribution of transmitted potentials. With a 3-subject connection, however, the potentials of N0, N3, N6 and N9 were recorded from the two non-stimulated arm to the first subject. In this recording, there may be some contribution of P9 transmitted to the third subject from the non-stimulated arm.

(Fig. 11). The potentials recorded from the knee to knee or ankle to knee derivations varied depending upon the location of the pad electrode. With connection at the upper arm, N3, N6 and N9 were recorded. Of the three, N6 was largest. With the shoulder connection N9 was larger than N6, and N3 was not present. When the connection was from the neck, N6, P9 and perhaps cervical N13 were transmitted. These differences appropriately reflected the potential gradient at the location where the potentials were transmitted. The transmitted potentials from the ankle and knee were nearly equal or even larger at the ankle despite

close proximity of the knee electrode to the connecting strap. No potentials were recorded from the iliac crest.

We then tested the distribution of the transmitted potentials by recording from longitudinally placed electrodes along the entire leg (Fig. 12). With placement of the connecting strap below the knee, the transmitted potentials were evenly distributed distally, but quickly dissipated proximally. Even when the connecting strap was above the knee, the potential was larger at the distal leg. The findings contrasted to the transmission to the third person where the potentials appeared to be distributed evenly.
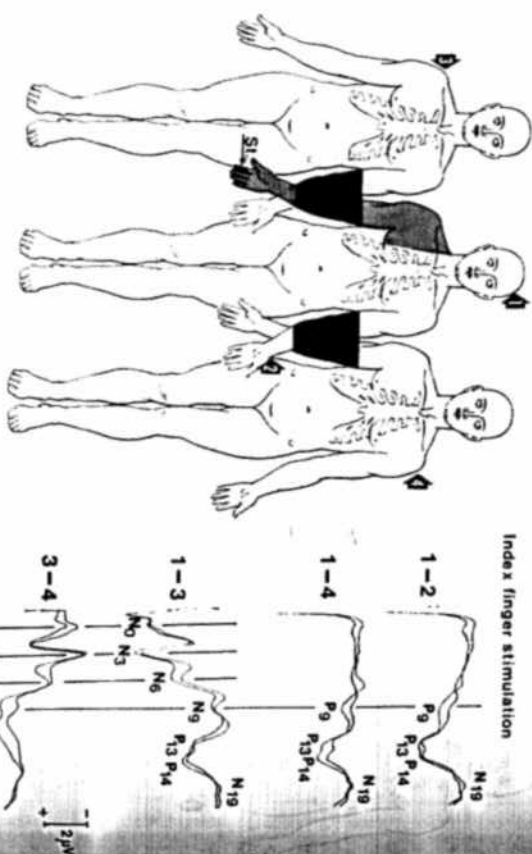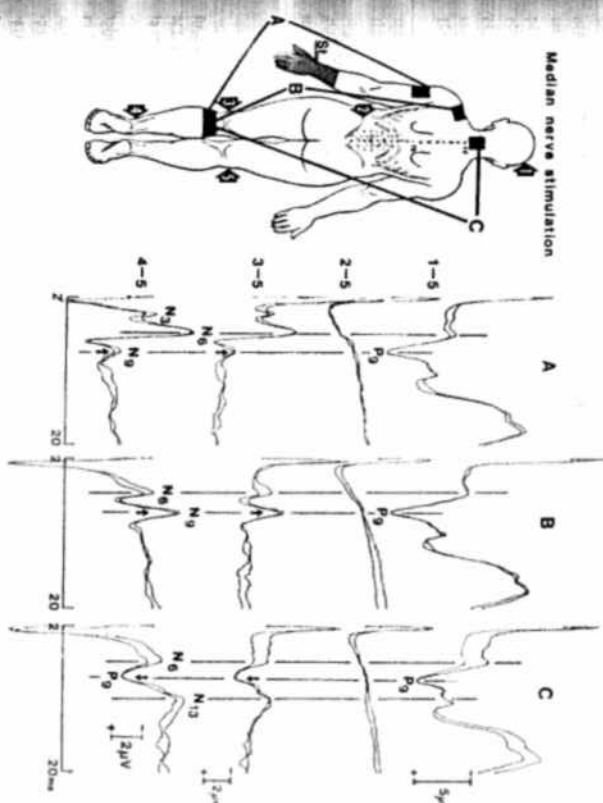

Median nerve stimulation

Fig. 11. Transmission of potentials through the stimulated subject. Normally knee-knee (3–5) or ankle-knee (4–5) derivations registered no responses. When the electrical connection was made between upper arm and knee (A), either knee or ankle referenced to the opposite knee recording revealed well defined N3, N6 and N9 transmitted with connection from the shoulder (B). With the neck connection (C), N6, P9 and perhaps cervical N13 were transmitted. These recordings appropriately reflected the field distributions of stationary potentials from where they were derived. Despite a longer distance from the connecting strap to the ankle (4) than to the knee (3), the transmitted potentials were larger at the ankle-knee (4–5) than knee-knee (3–5) derivation. No potentials were recorded from the iliac crest to knee (2–5) recording.

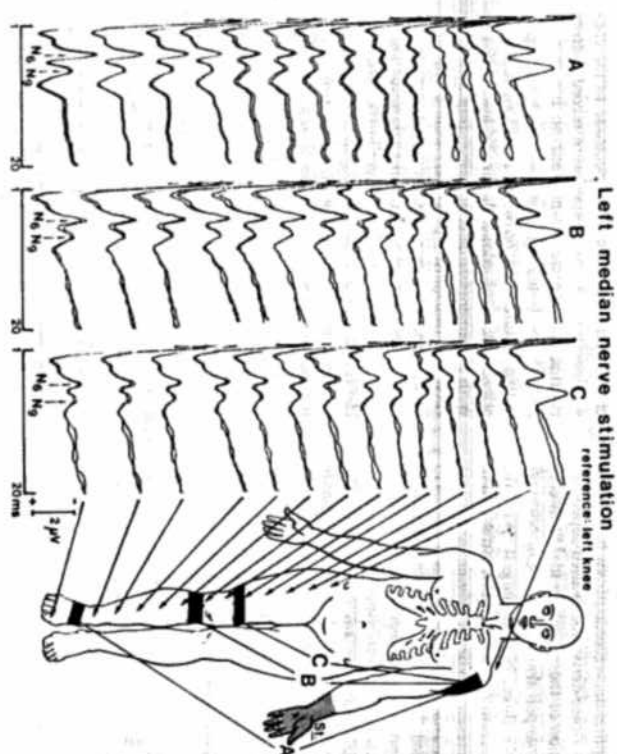Left median nerve stimulation
reference: left knee

Fig. 12. Transmission of potentials from the deltoid to different levels of the leg. Regardless of the location of the connecting strap at foot (A), below knee (B) or above knee (C), the transmitted potentials, N6 and N9, tended to be smaller at the proximal leg. This contrasted to the diffuse distribution of transmitted potential to the third person. Limited distribution of transmitted potentials within the stimulated subject may be due to the presence of positive counterpotential proximally.

Discussion

Following stimulation of the median nerve, 4 positive peaks, P9, P11, P13 and P14, are recorded from the scalp with non-cephalic references. They are considered far-field potentials and are attributable to the neural structures along the somatosensory pathway. Based on the conduction time from the wrist to the shoulder, for example, P9 has been thought to arise from the distal part of the brachial plexus. It is not known, however, why the traveling nerve impulse along the first order afferents gives rise to a stationary positive field in the absence of fixed neural discharges. Far-field potentials from a traveling source are thought to reflect an area of positivity moving in front of a nerve impulse as it approaches the recording electrode (Woodbury 1965). Desmedt et al. (1983) have shown that a postural change altering the angle between the arm and the shoulder can influence the latency value of P9 obtained in median SEPs. Studying action potentials of bullfrogs' sciatic and peroneal nerves using 'fluid electrodes', Nakanishi (1982) has shown that stationary peaks occur where the resistance of the conduction media changes abruptly. Based on this finding it is postulated that far-field potentials of median SEPs are generated at such fixed sites. In our recent studies, we observed stationary potentials which are temporally related to the arrival of

antidromic impulses at the base of the digit and at the wrist after activation of the median or radial nerve. P0-N0 shown in this study (Fig. 4) corresponded with the potential generated at the wrist. These findings suggest that the stationary potentials are derived at least in part from changes in the current flow within the volume conductor based upon the shape and the conducting properties of the surrounding medium (Kimura et al. 1983, 1984).

In surface recordings from a nerve, connective tissue and interstitial fluid act as conductive media or volume conductors. Buchthal and Rosenfalck (1966) showed that the position of the recording electrodes within the volume conductor alters the complex response on the postero-lateral surface of the arm after stimulation of the median, ulnar or radial nerve. In the present study, we found a similar situation when recordings were made with the reference at the knee. In the referential recording with active electrodes over the nerve trunk, the potentials were multiphasic, apparently due to the amalgam of stationary peaks and propagating nerve impulses. Bipolar recordings with short interelectrode distances effectively cancelled the stationary peaks, giving rise to a 'pure' nerve impulse. When recording electrodes were placed on the lateral aspect of the arm, even referential derivations yielded 'pure' stationary peaks presumably because the impulses propagating along the nerve trunk had little influence on the recording electrodes.

With this recording technique, we have found 3 stationary peaks, N3, N6 and N9, which are distributed widely over the stimulated arm after median nerve stimulation. The amplitude of N9 was maximum at the shoulder and its latency matched precisely the well described P9 potential recorded from the scalp with non-cephalic references. The finding indicates that there are stationary negative peaks located near the generator of the positive counterfield of P9 which, in turn, extends from the scalp to the opposite arm and to the mid-thoracic region.

In contrast to the N9-P9 relationship where N9 appears near the generator source and P9 is recorded from the scalp, no positive field counterpart for N6 is found at the scalp. Instead, N6 extends to the scalp. Close scrutiny of the potentials recorded from the trunk with the reference at the big toe, however, revealed phase reversal of N6 below the mid-thoracic level which suggests that there is a positive field for N6 in the lower half of the body. We failed to reveal a positive counterfield for N0 or N3 despite extensive effort using a variety of electrode derivations. However, this does not necessarily rule out the presence of a positive field for N0 or N3, since we are dealing with recorded potentials relative to a reference within the same volume conductor.

The transmission of stationary negative peaks and far-field positive potentials to another person was a serendipitous finding discovered while attempting to create sufficiently 'indifferent' reference. This, in turn, supported the presence of the stationary peaks N3, N6 and N9 over the stimulated arm and P9 on the opposite arm. One tends to regard far-field peaks as monophasic positivity registered by a distant electrode beyond the termination of the active fibers which 'looks' at the moving front of depolarization (Lorente de Nó 1947; Woodbury 1965; Arezzo et al. 1979). Our finding indicates, however, that this assumption is not necessarily valid. Distribution of the transmitted potential over the entire body of the non-stimulated subject suggests that a volume-conducted potential can spread a much further distance than has been commonly believed as long as an appropriate conductive medium is available. The limited spread of transmitted potentials from the arm to the leg within the stimulated subject may be due to cancellation of the transmitted negative peaks as they approach the positive potentials in the trunk.

As has been suggested by Kimura et al. (1983, 1984), an apparently standing potential may result because of a sudden change in current density between one volume conductor and another, N3 and N6 stationary peaks indeed appear to rise when the traveling impulse enters the forearm

muscles and deltoid respectively. N9 may result when the impulse reaches the boundary between the body and arm. It seems plausible that a negative stationary potential is necessary to give rise to a positive far-field potential. If far-field potentials are defined as potentials recorded at a distance from their generator source, negative stationary potentials may also be regarded as far-field potentials since their field may spread far beyond the territory of the nerve impulses. In agreement with this concept, Emerson et al. (1984) have recently shown that the traveling cervical waves are accompanied by 2 negative far-field potentials, N10 and N12, recorded at the scalp following stimulation of the median nerve. Also cervical N13 has been found to have fixed latency from the C7 to C2 spines (Kimura et al. 1978; Desmedt and Cheron 1981; Lueders et al. 1983). Similarly, the N24 peak recorded at the T12 spine after stimulation of the tibial nerve at the ankle showed little latency shift from lumbar to caudal thoracic spine. The spinal potential at the caudal lumbar spine often had double peaks with the second peak corresponding to N24 (Yamada et al. 1982, 1984). Hence, N13 and N24 may represent stationary negative field potentials nearby the generator instead of traveling impulses. Incidentally, corresponding positive far-field potentials have been identified for N13 (Desmedt and Cheron 1981; Emerson et al. 1984) and N24 (Yamada et al. 1982; Desmedt et al. 1983).

We propose that the positive far-field potentials recorded from a distance are reflections of stationary fields of negativity located near their generators. The stationary negative peaks may be generated where traveling impulses arrive at a change in volume of the tissues surrounding the nerve. Since N3, N6 and N9 can be easily recorded as positive potentials from the scalp when referenced to the dorsum of the stimulated arm, clinical application of the technique may help elucidate further the physio-anatomical nature of these stationary negative potentials and their relationship with far-field positive potentials.

Summary

We studied the field distribution of referentially recorded negative potentials after stimulation of the median nerve at the wrist in 15 normal subjects. When recorded from multiple sites along the lateral aspect of the arm with the reference electrode at the knee, 3 negative peaks, N3, N6 and N9, appeared at fixed latencies. Of these N3 and N6 were highest in amplitude at the distal insertion of the brachioradialis and the distal end of the deltoid, respectively, and N9, at the acromion.

With stimulation of the finger, the negative peaks shifted in latency by about 3 msec, indicating an anatomically fixed generator source for each component. When compared to far-field potentials, N9 was of the same latency as scalp recorded P9, that extended to the arm contralateral to the side of stimulation and to the upper half of the trunk. In contrast, N6 extended to the scalp with P6 spreading to the lower half of the body.

When two subjects were connected by the arm, stationary negative or positive peaks were transmissible from the stimulated to the non-stimulated subject. When the stimulated arm of the first subject was in contact with the second subject, N1, N6 and N9 were recorded in the latter. Only P9 was registered when the unstimulated arm was in contact with the second subject.

We conclude that N3, N6 and N9 are stationary negative potentials generated at certain points along the nerve pathway, probably representing a negative counterfield for positive far-field peaks, P3, P6 and P9. These stationary potentials can spread widely in a volume conductor and can even be detected in a non-stimulated subject making a close contact to the generator source.

Résumé

Potentiels négatifs stationnaires proches de la source et potentiels de champs lointains à distance

Nous avons étudié la distribution de champ de potentiels négatifs enregistrés par rapport à une référence après stimulation du nerf médian au niveau du poignet chez 15 sujets normaux. Lorsque les enregistrements ont été effectués en différents points situés le long de la face latérale du bras et en référence à une électrode localisée au genou, 3 pics négatifs sont apparus, à latence fixe, N3, N6, N9. N3 et N6 présentaient respectivement une amplitude maximale à l'insertion distale du brachioradialis et à l'extrémité distale du deltoïde, et pour N9, à l'acromion.

Avec une stimulation du doigt, la latence des pics négatifs glissait d'environ 3 msec, indiquant que chaque composante possédait une source génératrice anatomiquement fixe. Lorsqu'une comparaison était faite avec les potentiels de champ lointain, N9 possédait la même latence que l'onde P9 du scalp, qui se propageait au bras controlatéral à la stimulation et à la moitié supérieure du tronc. En revanche, N6 s'étendait au scalp avec P6 envahissant la moitié inférieure du corps.

Lorsque deux sujets se tenaient par le bras, les pics positifs et négatifs se transmettaient du sujet stimulé au sujet non stimulé. Lorsque le bras stimulé du premier sujet était en contact avec le second sujet, N3, N6 et N9 étaient enregistrés chez ce dernier. Seule P9 était enregistrée lorsque le bras non stimulé du premier sujet qui se trouvait au contact du deuxième sujet.

Nous concluons que N3, N6 et N9 sont des potentiels négatifs stationnaires produits en des points précis des voies nerveuses, représentant probablement un champ négatif correspondant aux pics positifs de champ lointains, P3, P6 et P9. Ces potentiels stationnaires peuvent s'étendre largement dans un volume conducteur et peuvent être détectés chez un sujet non stimulé placé en contact étroit avec la source génératrice.

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HABITUATION OF THE BLINK REFLEX: COMPUTER ASSISTED QUANTITATIVE ANALYSIS [1]

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The electrically induced blink reflex (BR) dis-
plays decreasing late responses if repeated stimuli
are delivered. This behaviour, defined as habitua-
tion, is strongly dependent on stimulation
frequency and intensity as well as on intrinsic
factors, e.g., the state of arousal (Thompson and
Spencer 1966; Groves and Thompson 1970; Malin
et al. 1980). Moreover, it depends on previous
excitation via different inputs to the interneurone
pool such as the common final relay for the blink
reflex afferents from trigeminal, acoustic and vis-
ual pathways (Rimpel et al. 1982).

Quantification of habituation, however, is dif-
ficult to evaluate because of the great variability of
the individual traces in latency, amplitude, shape
and duration due to different motor unit discharge
patterns (Dengler et al. 1983). Up to now, to our
knowledge, only some attempts have been made to
quantify the EMG activity of the BR, integrating
single responses (Dehen et al. 1976) or serial trials
after electronic summation (Dengler et al. 1982a,
b; Kossev et al. 1983).

In the present study a computerized analysis of
reflex responses was performed in 20 healthy sub-
jects, applying trains of stimuli of various frequen-
cies. To estimate the degree of habituation the
latencies, reflex durations and response areas were
taken into account.

Methods

The blink reflex (BR) was elicited by stimulat-
ing the supraorbital nerve through fixed surface
electrodes. Constant current square wave pulses of
0.2 msec duration were delivered unilaterally, ad-
justing the stimulus intensity for maximal ampli-
tude. Reflex responses were recorded with surface
electrodes at the middle of the lower eyelid with a
lateral reference on each side and fed to a differen-
tial amplifier using a bandpass from 300 Hz (6
dB/oct.) to 3200 Hz (12 dB/oct.).

Data processing was performed by an IN-110
computer, checking the stimulating frequencies and
pauses automatically. Three different trains of 10
stimuli each, with decreasing frequencies, inter-
rupted by pauses were delivered to each side. The
registered signals could be observed on a
program-controlled graphical display unit for con-
trol purposes and were stored on disc for the
following investigations. The stimulus artifact was
eliminated by setting the first 6 msec to zero.

To reduce the signal spectrum to the area of
interest for further analysis and to get a clear-cut
baseline a multiplying Hanning window in the
frequency domain was used. By this signal fre-
quencies below 100 Hz and above 1500 Hz, as well
as secondary oscillations (Gibb's phenomenon)
which may appear using a rectangular window of
the same frequency range, are eliminated (Fig. 1B,
C).

In the next step a derivation of the signal by
time (Fig. 1D) was set up to improve the signal to
artifact ratio, because volume-conducted biological
artifacts arising from neck or masseter muscles
have small amplitudes and plain slopes.