Chapter 4
Sensory Studies

John C. McHugh

Introduction

Sensory nerve conduction studies in children are generally well tolerated and easy to perform. It is intended that this chapter be read in conjunction with Chap. 5 (motor nerve conduction studies) in order to gain an overall view of nerve conduction studies (NCS) in children.

Many authoritative texts already describe NCS techniques in great detail in adults, therefore this discussion will focus on the studies as they pertain to children [1, 2]. The overall technical details will of course be similar but important differences exist when performing and interpreting NCS in adults compared to children. For example, the relatively smaller distances being measured in children have the potential to have a greater proportional impact upon the calculations of latencies and conduction velocity. There is also an even greater need for empathy and kindness when performing neurophysiological testing upon the pediatric patient. Lastly there is a need for careful advanced planning since neurophysiological testing in children may need to be limited to the absolute minimum number of studies required to answer the clinical question. While the latter points may also be applicable for adult patients, it is particularly relevant for children who may show less tolerance of the test particularly when pathology is present and as such higher stimulation intensity may be required.

J.C. McHugh, MB, BCh, BaO, M.D., M.R.C.P.I.
Department of Clinical Neurophysiology, Our Lady's Children's Hospital,
Crumlin and AMNCH, Academic Unit of Neurology, Trinity College Dublin, Dublin, Ireland
e-mail: John.McHugh@olchc.ie

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Strategic Planning

Despite the advances of molecular testing over the last decade, the overall use of EMG/NCS in children <18 years old continues to rise, although a recent review noted that the demand for EMG testing in younger children (<5 years old) may have diminished [3]. Most referrals stem from neurologists, both from specialists and non-specialists in neuromuscular medicine. The remaining referrals are received from orthopaedic surgeons, rheumatologists, pain specialists and other physician groups. The most common reasons for referral are evaluation of polyneuropathy or mononeuropathies followed by evaluations of symptoms affecting multiple limbs (e.g., weakness or pain).

The starting point for planning a set of NCS is to ensure that a specific clinical question is posed [4]. Clinical history and physical examination must guide the testing that is to be performed since neurophysiological testing is essentially an extension of the physical examination. Most neurophysiologists or neurologists will first attempt nerve conduction studies and electromyography (NCS/EMG) on an awake or non-sedated child. Most children will typically tolerate electrophysiological testing unless there is a comorbid diagnosis (e.g., autism, severe global developmental delay) that creates a barrier to physician-patient communication, or severe anxiety and/or pain may limit testing. The time spent obtaining a history and performing a clinical examination also affords the physician an opportunity to establish rapport with the child or adolescent and gain his/her trust. This may be particularly helpful where anxiety and/or apprehension are factors.

Laboratories may have guidelines and/or protocols that are intended for use in patients with specific clinical problems. However, the NCS/EMG in children must be tailored according to: (1) the question posed by the referring physician; (2) the individual child's clinical signs and symptoms and; (3) the likelihood that he/she will tolerate electrophysiological tests required to answer the clinical question. For these reasons it is important to plan the study in advance. One helpful way of determining how to prioritize the order in which nerves will be studied for a particular problem is to ask; "If this study must end prematurely what is the minimum number of nerves in descending order of importance that must be tested to answer the clinical question?" Posing such a question allows a pragmatic and rational study to take shape and is a useful mental exercise. Even if such scenarios are not frequently encountered it nevertheless maximizes the likelihood that valuable information can be obtained.

Sensory nerve conduction studies are the most rational starting point for almost all electrophysiological studies. Since most sensory nerves are located superficially they require low stimulation intensity compared to motor nerve studies. Much information is to be gained from intact lower extremity sensory nerve action potentials (SNAP) as normal amplitude, morphology and velocity are extremely helpful at excluding a length-dependent, large-fiber polyneuropathy. However, even for clinical problems involving sensory symptoms and/or areflexia it is typically necessary to pursue additional testing. Intact SNAPs and absent or reduced motor responses may lead to speculation about a neuronopathy (including motor neuron disease), myopathy, or certain disorders of the neuromuscular junction. In a patient presenting with weakness, the finding of reduced or absent SNAP assists in localizing the

lesion distal to the dorsal root ganglion (i.e., within the distal nerve root or anterior primary ramus, plexus or peripheral nerve) [5]. Reduced SNAP amplitudes are not consistent with a primary disorder of motor neurons or a primary disorder of muscle or neuromuscular transmission. In this manner the NCS/EMG study will proceed iteratively and can adapt to the findings in a way that integrates knowledge and narrows down potential clinical differential diagnoses.

First Impressions—How to Approach the Child and Parents

It is advisable that some written information should be forwarded to parents in advance of NCS regarding the nature of the test. It is useful to describe the environment of the test and estimate roughly how long the test should take. Effort on these points ahead of meeting the patient can go a long way to achieving some calm at the time of the appointment. The neurophysiologist should introduce himself/herself to the child and to the parents, making particular effort to allow the child to feel comfortable in the environment.

Parents and children will want to know what the testing involves and what it will feel like. In covering these points, it is important to balance their need and right to information about the test with the potential for creating unmerited apprehension particularly in regard to the tolerability of the test. For nerve conduction studies, it is my practice to avoid using the words: electrode, stimulator and shock. Instead, I prefer to use the terms: sticker, battery and pulse, zap or tickle. When asked if the test is going to hurt it can be useful to liken the sensation one feels when they bang their funny bone or after one walks on a carpet and touches a door handle.

Consent

Written consent is not a requirement for non-sedated NCS in most if not all institutions and any effort to introduce more formal consent procedures for reasons of propriety only serves to increase parental anxiety in the author's view. After explaining the test and the reasons for carrying it out, there is value for the neurophysiologist to begin and work quickly to complete the test. This must be carried out with a calm demeanor so as to avoid the appearance of being rushed or worse still actually rushing the test.

Getting Started

Invite the child to sit with the parent during the test. Older children are usually comfortable sitting by themselves on the examination chair or table. For children under five, it is often helpful to ask them to sit on a parent's knee. For all children, it is

advisable to ask them to remove their shoes which has the three-fold benefit of allowing accurate measurement of height before the test, exposing the feet for testing where needed, and minimizing consequences of being kicked during the study.

For babies, it is typically best to carry out studies in the arms of a parent or caregiver, though a cooperative infant may tolerate studies on an examination table. The use of swaddling during the test can minimize unwanted movement artefacts but also acts as a comfort measure and can even facilitate sleep in very young patients. The use of feeding during a test may also help to pacify a young baby, although in general it is the author's preference to avoid this unless it is necessary.

Establishing a rapport with the child and his/her parents is invaluable to the examination. One cannot be too prescriptive on this point. To some extent there is an individualized approach for everyone when it comes to dealing with children. This will be a reflection of the neurophysiologist's own personality, age and level of experience with children. Within the room, toys, teddy bears and stickers may provide helpful diversions and incentives for younger children. For the older ones, ready-made distraction is available by talking about the equipment itself. Most children over the age of six (and many below) will engage with the idea of playing a game using the EMG computer. It may be worth noting that most small handheld electronic devices including phones do not generate 60 Hz artifact or other appreciable electrical artifacts with standard filter settings.

Pre-test Measurements and Considerations

Height should be measured routinely in all cases before NCS. In contrast to adults, in whom SNAP amplitudes diminish to some small extent in the very tall, height is not directly important for understanding sensory NCS in children [6]. However, it is relevant to some parameters in motor NCS (Chap. 5) and therefore it should be registered before testing.

It is important to have a thermometer available for measurement of skin temperature. Temperature affects the velocity of conduction for large fiber sensory and motor nerves such that cooling of a limb diminishes conduction velocity and warming increases it [7]. The duration and area of the recorded potentials are also affected such that a broader potential of increased area is obtained at lower temperatures and this can be modeled in a linear fashion. Temperature also has an effect on the amplitude of compound nerve or muscle action potentials such that amplitudes tend to be larger during cooling although the relationship is non-linear. The optimal skin temperature for NCS is ≥32 °C at the wrist and ≥30 °C at the ankle. Warming of limbs should be undertaken when skin temperatures are below this level. In reality, many laboratories do not routinely engage in limb warming pre-test unless the peripheries are very cold and precise measurement of conduction velocity is essential, e.g. to distinguish a demyelinating from an axonal neuropathy based on strict velocity criteria. Whilst making this differentiation is usually straight forward in most cases, borderline conduction velocity slowing in the setting of cold peripheries and small SNAPs poses a problem and limb warming might need to be considered in such instances.

Although short term effects on conduction velocity can be observed after 2–3 minutes of limb immersion in warm water, more rigorous studies reveal that longer durations of immersion are required to achieve adequate warming of nerve [8]. For this and other reasons, a practical suggestion is to aim to avoid cold limbs by keeping room temperature warm and allowing the patient sufficient time to acclimatize to being indoors before carrying out the study. Furthermore, although subject to theoretical objections, the use of a correction factor can be considered (adding 4% of the measured sensory conduction velocity for every degree below the minimum expected value). For a more in-depth exploration of temperature and its implications for NCS please refer to Chap. 11 (Artifacts) and/or the excellent minimonograph of Denys [7].

Brief Overview of Physiology and Equipment

The basic operations of all EMG machines are similar. To perform nerve conduction studies, there is an electrical stimulator which comprises a cathode (negative pole) and an anode (positive pole). The flow of current between the two poles induces localized changes in the distribution of charge across the underlying nerve membrane such that the nodal portion of membranes beneath the cathode becomes relatively more positive intracellularly. This depolarization from resting membrane potential is what triggers the nerve action potential to occur at nodes of Ranvier adjacent to the cathode. The action potential will propagate itself in both an antidromic and orthodromic direction along the nerve. Antidromic sensory nerve conduction studies occur when an action potential travels in the opposite direction from the normal physiological afferent sensory response. Orthodromic nerve conduction studies occur when the action potential is propagated in the normal physiological direction. The latter is particularly useful for eliminating motor artifact in mixed nerves of the hand and/or feet. Surface electrodes are placed over the skin in an area corresponding to the normal physiological course of a specific sensory nerve. Many laboratories tend to rely primarily on either antidromic or orthodromic sensory studies for the most commonly studied nerves, but others use a standardized mix of the two approaches.

Stimulating electrodes vary in design. Bar electrodes are encased in molded plastic and have a fixed spacing between anode and cathode. In pediatric NCS, it is usually necessary to have at least two sizes available: studies in patients over 18–24 months can be achieved using conventional adult stimulators with spacing of 2–3 cm between anode and cathode; studies in newborns and infants ideally require smaller stimulators (1 cm spacing or less) [9]. Ring electrodes can be used for digital stimulation. Subcutaneous needle stimulation with surface anode (e.g., for lateral femoral cutaneous nerve of the thigh) can be helpful in some instances but is not used commonly in children and as such will not be discussed further here. A well-equipped laboratory that performs studies in children should have an array of different surface electrodes available for different circumstances.

A supramaximal stimulus is one which is sufficient to stimulate all of the large fiber axons within the nerve such that a compound nerve action potential is measured,

meaning that its amplitude cannot be augmented by further increases in stimulus intensity. For sensory studies, short duration (usually 0.1 ms) square wave pulses are increased to achieve a maximal sensory nerve action potential (SNAP). In children, discomfort is reduced by having some appreciation of the range of stimulus intensities that is likely to produce a supramaximal SNAP for each nerve at a given site. In this way, the number of stimuli can be kept to a minimum. As a very simple guide, sensory stimulation (at 0.1 ms durations) should rarely be increased beyond 40–50 mA in a child, and never beyond 10–20 mA in the digits. For many sensory nerves, supramaximal SNAPs will be achieved at stimulus intensities of 10–20 mA but this, of course, varies according to: the specific nerve and site; the density and volume of intervening soft tissue; and the degree of myelination (which is influenced in turn by age and by the presence of nerve pathology).

SNAPs are recorded using active and inactive surface electrodes, otherwise referred to as G1 and G2 or (sometimes E1 and E2) where E is short for electrode and G refers to grid. These are placed in line on the skin overlying the nerve of interest. The recorded wave-form is usually triphasic comprising a positive, negative and then a second positive component. This is produced by the passage of the action potential through a tissue volume conductor, which can be modelled simply as a cylinder with positive-negative dipoles at its leading and trailing end [10]. The direction of the recorded potential difference is determined by what E1 (G1) sees relative to E2 (G2) at a given time and this will change with movement of the dipole towards and then away from the recording electrode pair. The shape and relative amplitudes of the three phase-components is determined by the orientation, inter-electrode spacing and distance of the surface electrodes relative to the action potential generator, i.e., the nerve. These factors are controlled for by the rules which govern electrode placement, which will be discussed below. Of note, a simpler biphasic potential (the norm for compound muscle action potentials in motor studies) can also be seen in some sensory studies, for example in antidromically recorded digital SNAPs; this occurs because of the peculiar effects of positive far field potentials (as opposed to local potentials) [10]. When these arise, they are seen equally by active and inactive electrodes and accordingly they do not register as a potential difference—therefore the first visible potential difference appears to arise directly under E1 (G1) and not in advance of it.

Shock artifacts are visible in every sensory recording in children. Indeed the absence of shock artifact should alert the neurophysiologist to some form of recording failure; the most common reason for this being disconnection of the recording leads to the amplifier after cleaning. The relatively short distances between stimulating and recording electrodes in children is a technical difficulty since spread of the shock artifact more readily contaminates the potential of interest and in some instances can obscure it entirely. Electrical isolation of the stimulator is a feature of most modern EMG machines which helps to reduce shock artifact, as does the use of shielded cables for stimulation. Other measures which can be adopted in the pediatric EMG laboratory include: avoiding excessively short distances between stimulus and recording sites; using alcohol-rubs to dry the skin before testing to reduce skin impedances; changing the surface electrode stickers; placement of the

ground electrode between stimulating and recording electrodes. On rare occasions it may be necessary to further reduce skin impedance by gently abrading the skin before testing, however this is a technique used primarily in adults and is not generally recommended for children. Another tip which can be useful in situations of particular difficulty is to change the shape of the stimulus from a monopolar to biphasic square wave; this can also remove or alleviate shock contamination but should not be relied upon as an alternative to scrupulous skin preparation and electrode application.

Nerve Selection

The question of which nerve(s) to study is influenced primarily by the clinical question that is to be answered. However, some age-related factors must also be considered. For infants the sensory nerves that are routinely studied include: median, ulnar and medial plantar nerves. In children and adolescents the sensory nerves that are routinely studied include: median, ulnar, dorsal ulnar cutaneous, radial, superficial peroneal and sural nerves. Less commonly the lateral and medial antebrachial cutaneous nerves can be studied.

Electrode Placement for Sensory NCS

The positioning of stimulating and recording electrodes should be anatomically the same in children as for adult patients. The difference is that limb lengths vary considerably between child- and adulthood and therefore the distances between stimulating and recording electrodes in adults must be adjusted for the child. Therefore, in children it is more useful to position electrodes in relation to surface anatomical landmarks rather than at fixed linear distances.

The following section will deal with how to carry out sensory conduction studies in children for all of the commonly studied nerves. It should be noted that nerves can be stimulated in either direction—orthodromically or antidromically. There is no one correct method and in most instances ortho- or antidromic testing uses exactly the same electrode placements, simply swapping the stimulating and recording electrode pairs as required. The direction of recording does not affect nerve conduction velocity but the amplitude of sensory nerve action potentials (SNAPs) will vary depending on the approach used, and thus reference ranges may vary depending on which approach is adopted. In my own laboratory, a mixture of anti- and orthodromic testing is used: orthodromic testing is favored in the hands and in the feet, whereas antidromic testing is generally preferred at more proximal sites.

Illustrations of electrode placements are provided in Figs. 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 and 4.9. Tables 4.1 and 4.2 provide descriptions of electrode placements for both antidromic and orthodromic approaches.

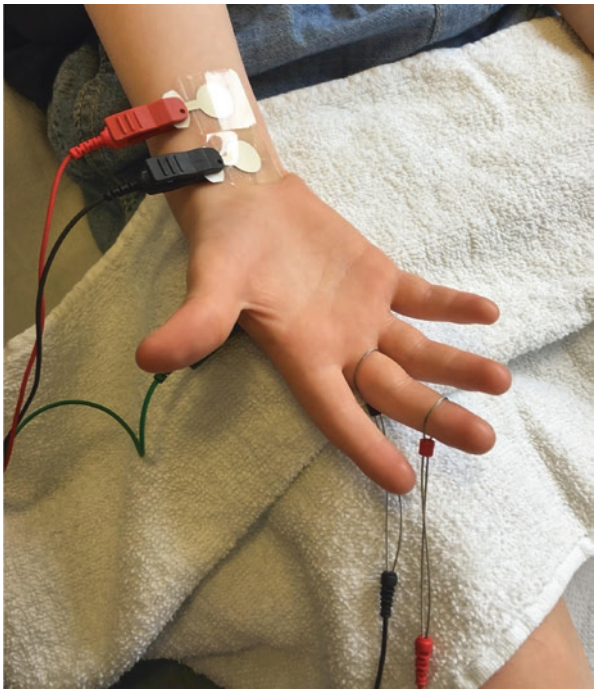

Fig. 4.1 Median digit III orthodromic study recording over the median nerve at the wrist and stimulating digit III

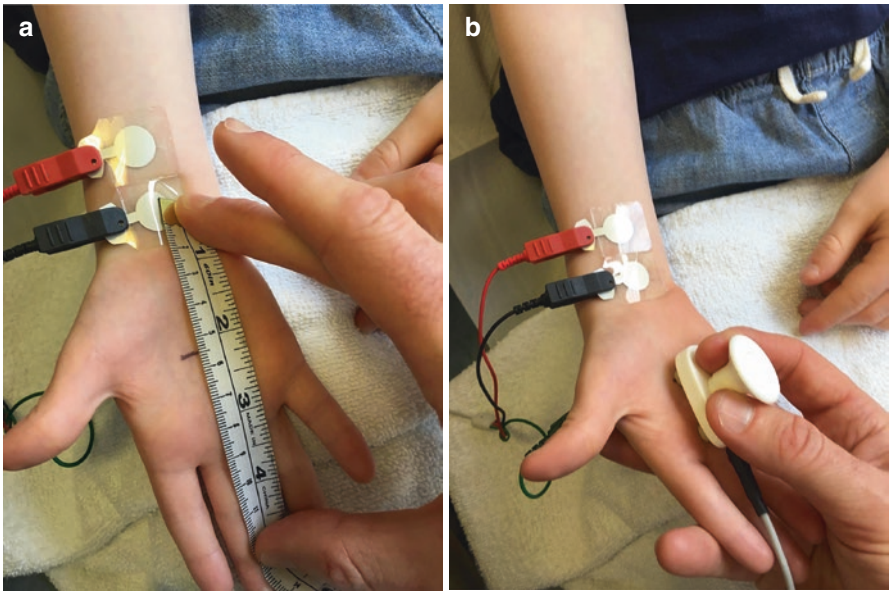

Fig. 4.2 (**a**, **b**). Median palmar sensory study (orthodromic) recording over the median nerve at the wrist and stimulating at the mid-palm (**a**). This is located at the mid-point of a line drawn between the proximal wrist crease and the proximal interphalangeal (PIP) joint skin crease of digit III (**b**)

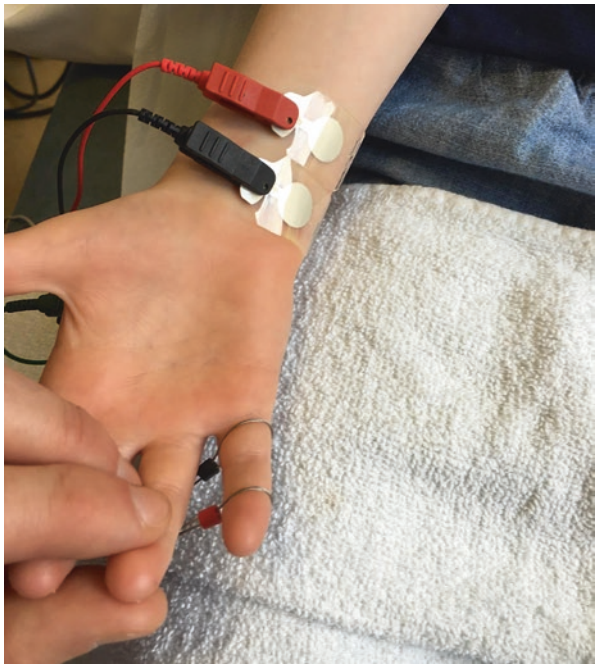

Fig. 4.3 Ulnar digit V orthodromic study recording over the ulnar nerve at the wrist and stimulating digit V with ring electrodes

Stimulation and Recording

In adults, it is customary and acceptable to average the recorded sensory signal over a train of 5–20 stimuli to optimize the recorded waveform and facilitate measurement and marking of specific latencies and amplitudes. Some neurophysiologists use the repetitive stimulation setting at frequencies of 1–2 Hz to collect a reasonable number of potentials rapidly, thus needing only 5–10 seconds to acquire a single averaged SNAP. The same approach can be adopted in pediatric patients although some experienced practitioners advocate the use of single shocks in order to minimize discomfort and maximize compliance with testing. My view is that single supramaximal shocks may be adequate, particularly where the response is normal but I prefer to use averaging and to deliver repetitive shocks that increase from the point where a child can feel nothing to the point where they appreciate a "tickle". I find that it is useful to maintain stimulation at this level for a few seconds to gain the child's confidence and disperse any lingering parental anxiety about the test. I then play a game with the child, encouraging them to inspect the baseline noise as it waves on the screen (I refer to it as "the sea"). I invite the child to tell me when they see a dolphin or other sea creature emerge from it. As I increase the stimulus to the point where the SNAP becomes visible, I whisper that it will be a bit "ouch" for just a second, then quickly increase to supramaximal and finish stimulation by marveling at how large the response is (at least in cases where the SNAP is recordable). It is important that

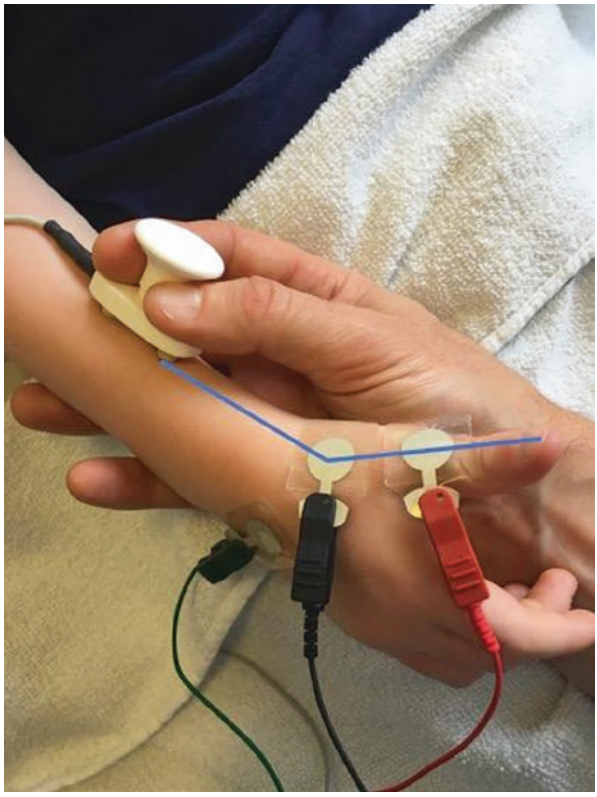

Fig. 4.4 Superficial radial antidromic study. The distance between cathode and G1 is approximately the same as the distance from G1 to the tip of the thumb

the first nerve study should succeed as it lays a platform of confidence which permits further testing to occur. If this approach is unsuccessful, especially in infants and younger children who may not fully comprehend such interactions, an alternative approach is to capture two similar individual SNAPs and display them separately on the report to convey to others that the SNAP is reproducible and not artifactual.

The sweep speeds, screen amplification and filter-settings can be changed easily on digital machines (belying the decades of development and technological sophistication that have culminated in modern EMG equipment). Amplification settings of 10 μV per screen division (10 μV/D) and sweep speed settings of 1 ms/D are a common default for sensory NCS. These can be changed or increased as necessary so as to optimize visualization and marking of the waveform on the screen. Default filter settings of 2 Hz–20 kHz are standard in NCS to reduce high frequency noise and low frequency artifacts [1].

Measurements in NCS are primarily concerned with only two things: size and speed. The size of the sensory nerve action potential (SNAP) provides an estimate of the number of healthy functioning sensory neurons within the nerve being tested. The sensory conduction velocity and associated latencies provide information that relates to the fastest conducting myelinated fibers within the nerve. NCSs are insensitive to

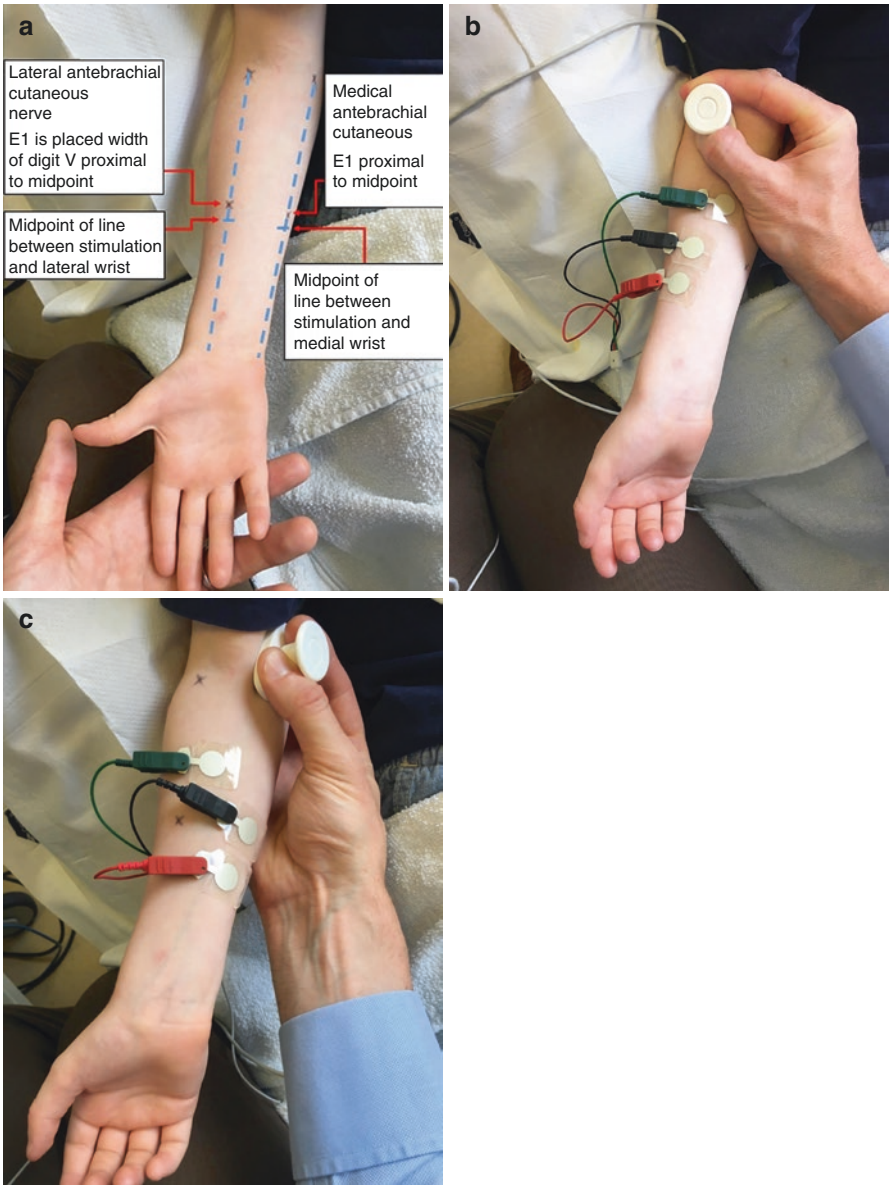

Fig. 4.5 (**a**–**c**). Limb measurements (**a**) for antidromic recording of lateral (**b**) and medial (**c**) antebrachial cutaneous nerves of the forearm

the functioning of small diameter and unmyelinated nerve fibers, the physiology of which must be interrogated by other means that will not be discussed here.

Size and speed in sensory NCS are described primarily in terms of amplitude (measured in microvolts; μV), and velocity (measured in meters per second; m/s). Other

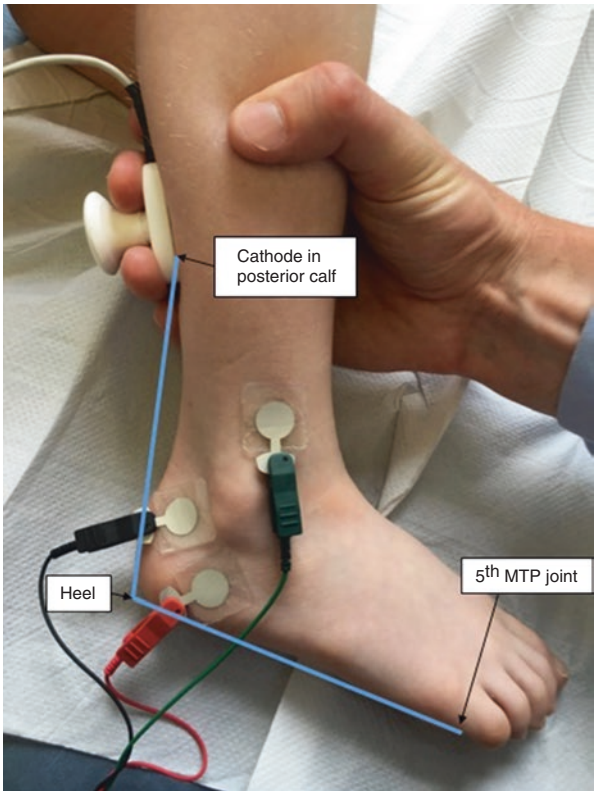

Fig. 4.6 Sural sensory antidromic study stimulating behind the calf, the same distance above the inferior heel as the 5th metatarsophalangeal (MTP) joint is anterior to it; recording is postero-lateral to the lateral malleolus

parameters include individual latency measurements, the shape of the waveform and its duration and area. These measurements are defined by placing markers of latency and amplitude on the compound potential; most modern EMG programs will do this automatically but the markers should be inspected routinely and edited if placed erroneously, especially in some antidromic sensory studies where an artifactual motor waveform sometimes appears. The computer analyzes the waveform and automatically defines latency of onset (for biphasic potentials), first and second positive and negative peaks as well as the zero-crossing line that follows the negative peak.

Calculations of velocity are derived from these measurements by dividing the distance between stimulating and recording electrodes by the time (in milliseconds) from stimulus to onset or peak. The specific latency chosen to calculate velocity varies between different laboratories. My preference is to mark onset latency (for biphasic potentials) or first positive peak latency for triphasic potentials; these correspond to the contributions of the fastest conducting fibers. An alternative practice is to choose the negative peak latency: this has the advantage of being more consistently identifiable but will underestimate the velocity of the very fastest axons contributing to the potential. Analysis of the duration and area of the negative component of the waveform provides a useful index of temporal dispersion, which will be increased in cases of demyelination.

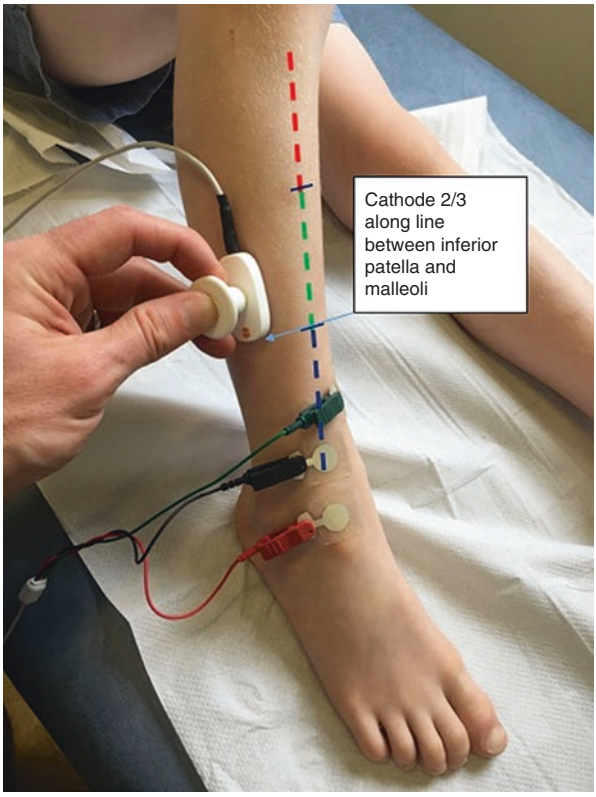

Fig. 4.7 Superficial peroneal sensory study stimulating over the lateral leg and recording at the ankle

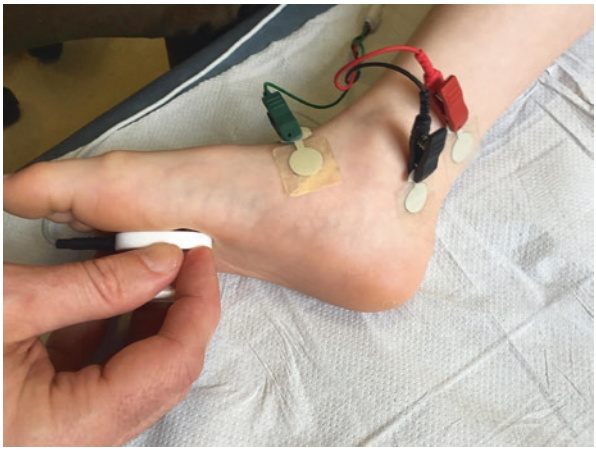

Fig. 4.8 Medial plantar orthodromic study stimulating at the medial arch (anode just proximal to the 1st MTP head) and recording behind the medial malleolus

Amplitude may be calculated in different ways: baseline to negative peak; from the midpoint of a "tilted" line connecting positive peaks to the negative peak; or from negative to positive peak.

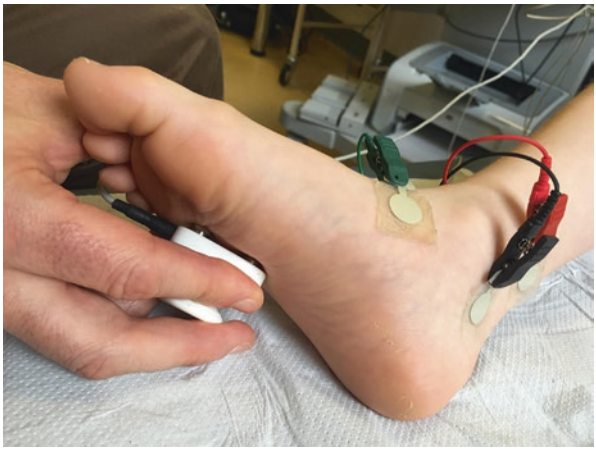

Fig. 4.9 Lateral plantar orthodromic sensory study stimulating over the lateral sole (between 4th and 5th metatarsal bones) and recording behind the medial malleolus

Table 4.1 Positioning of Electrodes for Upper Limb Sensory Nerve Conduction Studies

	Stimulation site	Recording site
Median nerve		
Antidromic	Stimulator placed at the wrist Cathode at wrist: between tendons of palmaris longus (PL) and flexor carpi radialis (FCR). Anode is located more proximally	G1 ring or surface electrode placed on digit II[a] G2 is 3 cm distal to G1
Orthodromic	Ring or bar electrode(s) on digit II[a] Cathode located at crease of first MCP joint. Anode is distal (between PIP and DIP joint) Digit I can be studied, but distance must curve around thenar eminence to reflect course of nerve	G1 surface electrode placed at the wrist (crease between tendons of PL and FCR) G2 is 3 cm proximal to G1
Palmar study *Orthodromic*	Stimulator placed on palm. In adults, cathode is located at the mid-palm, 7 cm from recording electrodes in a line with the webspace of digits II and III.	G1 is placed at the middle of the proximal wrist (as above) G2 is 3 cm proximal to G1
Ulnar nerve		
Antidromic	Stimulator placed at the wrist Cathode at wrist: just lateral to flexi carpi ulnaris (FCU) tendon. Anode is located more proximally	G1 ring or surface electrode placed on digit V[b] G2 is 3 cm distal to G1
Orthodromic	Ring or bar electrode(s) on digit V[b] Cathode located at skin crease of digit V MCP joint. Anode is distal (between PIP-DIP joints)	G1 over the medial wrist (just lateral to FCU tendon) G2 is 3 cm proximal to G1
Palmar *Orthodromic*	Stimulator placed on palm. In adults, cathode is located at the mid-palm, 7 cm from recording electrodes in a line with the webspace of digits IV and V.	G1 over the medial wrist at the proximal wrist crease (just lateral to FCU tendon) G2 is 3 cm proximal to G1

Table 4.1 (continued)

Radial nerve		
Antidromic	Stimulator place on dorsolateral radius. Cathode is 8-10 cm proximal to G1 in adult limb	G1 over superficial radial nerve as it crosses extensor pollicis longus tendon (base of 'anatomical snuffbox'). G2 placed over dorsum of first MCP
Orthodromic	Stimulator placed at skin crease of Digit I MCP joint. Anode is distal (at DIP joint skin crease)	G1 over radial bone at same distance proximal to the anatomical snuffbox as the tip of thumb is distal to it. G2 is 3 cm proximal to G1
Medial antebrachial cutaneous nerve		
Antidromic	Stimulator placed over medial elbow at mid-point between medial epicondyle and biceps tendon.	G1 surface electrode place in adults, 12 cm distal to cathode (along line between cathode and medial wrist). G2 is 3 cm distal to G1
Lateral antebrachial cutaneous nerve		
Antidromic	Stimulator place in antecubital fossa, just lateral to biceps tendon. *Note: low stimulation intensity < 15 mA is required. Cathode must be manipulated to reduce concomitant stimulation of the median nerve which causes a motor twitch*	G1 surface electrode place in adults, 12 cm distal to cathode (along line between cathode and radial styloid / lateral wrist) G2 is 3 cm distal to G1

PL, palmaris longus; *FCR*, flexi carpi radialis; *FCU*, flexi carpi ulnaris; *MCP*, metacarpal-phalangeal; *PIP*, proximal interphalangeal; *DIP*, distal interphalangeal
Mid palm, mid-point of line between proximal wrist crease and the PIP-skin creases
[a]Digit III or IV can also be studied (digit IV can be used for a median-to-sensory comparison study to investigate possible carpal tunnel syndrome)
[b]Digit IV can also be studied (digit IV can be used for median-to-sensory comparison study to investigate possible carpal tunnel syndrome)

Other important membrane parameters, such as nerve excitability parameters are beyond the scope of this chapter (see [Bostock et al.] for detailed review) [11]. The key points to remember when determining how to calculate amplitude and velocity are to maintain consistency and to use reference ranges appropriate for the approach.

Common Pitfalls

Many of the pitfalls that may arise can be avoided by attention to the measures already discussed above, particularly in relation to stimulation or shock artifact. Some additional problems that can be encountered include underestimation or over-estimation of conduction velocity, particularly in very young children and in

Table 4.2 Positioning of Electrodes for Lower Limb Sensory Nerve Conduction Studies

	Stimulation site	Recording site
Sural nerve		
Antidromic	Stimulator placed midline in dorsal, lower leg between heads of gastrocnemius. Cathode is at point below inferior belly of muscle with the cathode held firmly against the leg and angled slightly laterally	G1 posterior to lateral malleolus G2 is 3 cm distal to G1
Superficial peroneal nerve		
Antidromic	Stimulator placed 2/3 of the distance along a line drawn from the inferior patella to G1 (upper malleolus); this placement corresponds to 11–14 cm from G1 in adult limbs. Distance for optimal stimulation varies.	G1 upper level of lateral malleolus between the malleolus and tendon of the tibialis anterior. G2 is 3 cm distal to G1
Medial plantar		
Orthodromic	Stimulator placed such that the anode is proximal to the first metatarsal head (cathode is 3 cm more proximal almost at the mid-point of the sole). Stimulator should be held parallel and between first & second metatarsal bones. Alternatively, ring electrodes may be placed on Digit II	G1 placed posterior to medial malleolus; G2 is 3 cm proximal to G1
Lateral plantar		
Orthodromic	Stimulator placed such that the anode is proximal to the first metatarsal head (cathode is 3 cm more proximal almost at the mid-point of the sole). Stimulator should be held parallel and between fourth and fifth metatarsal bones. Alternatively, ring electrodes may be placed on Digit V	G1 placed posterior to medial malleolus; G2 is 3 cm proximal to G1

newborns. Notwithstanding the fact that newborns have slower conduction velocities because of incomplete myelination, the very small distances involved in testing young babies increases the margin of error in conduction velocity that can result from mismeasurement by even a few millimeters. This can produce erroneously slow or non-physiologically fast conduction velocities in this age group. Mismeasurement can be avoided by being consistent in the way that the limb is held and optimizing distances (gently stretching the ankle or wrist, or bending the elbow to maximize the distance between stimulation and recording) and more faithfully representing the actual course of the nerve.

Overstimulation is not tolerated by children. To insure acquisition of the most detailed study possible, it is important to start small and minimize the number of larger shocks. Conversely, it is important not to shirk from giving supramaximal stimulation sparingly since submaximal stimulation will falsely under-represent the nerve being studied and can lead to misdiagnosis.

Interpreting the Data

Understanding sensory conduction data can be challenging. Ideally each EMG laboratory should acquire its own normative data set over time. Despite standardization of technique and similarity of equipment, there will always be variations between different centers and different operators. Nevertheless, for those neurophysiologists who are establishing new laboratories, it seems sensible to suggest that they borrow established reference values from their training institution or alternatively they can refer judiciously to published datasets (see Chap. 24 for normal values). In such cases it is most important that they remain attentive to the techniques used (anti- or orthodromic) and to the age of the published population.

Sensory conduction velocities and sensory nerve action potentials (SNAPs) are significantly influenced by the age of the child: velocities effectively double from the time of birth to the age of 1–2 years, undergoing an especially sharp increase within the first 6 months of life. From 2 years of age onward a more modest increase will occur until adult velocities are achieved. A similar time-course and scale of maturation is also evident in SNAP amplitudes.

Understanding Abnormalities in Sensory NCS

Earlier it was indicated that when performing sensory nerve conduction studies, the neurophysiologist is interested primarily in two things: size (amplitude) and speed (onset latency or conduction velocity). This simplification holds true when it comes to interpreting the NCS data. Demyelinating nerve injury (acquired or hereditary) leads to slowing of nerve conduction velocities; it can also lead to conduction block which is discussed in more detail in the chapter on motor nerve conduction studies [12]. Demyelination will also produce changes in the duration and shape of the sensory nerve action potential (SNAP) since acquired as well as some inherited demyelinating neuropathies will affect some axons more than others giving rise to variable rates of demyelination which gives rise to a phenomenon of temporal dispersion. It can also increase the threshold for stimulation. However, these more subtle changes will not occur in isolation and therefore velocity reduction remains the primary parameter. Once again, it is stressed that temperature and age will both have independent effects on conduction velocity and must be taken into account.

Axonotmesis leads to a reduction in the SNAP amplitude due to the loss of sensory axons. In addition, the loss of axons will also result in a mild reduction (typically >75% lower limit of normal) of sensory conduction velocity.

Whilst the total number of nerves sampled in NCS in children may be less than a comparable study in an adult, it is nevertheless essential that sufficient data are gathered to answer the clinical question and to understand and characterize the pattern and distribution of any existing neuropathy.

Summary

Sensory nerve conduction studies in children are important in that they lay a platform for the rest of the electrodiagnostic study. Good technique and appreciation of the technical elements of the study are important and the challenges are undeniably greater than in adults. Reliable and accurate data can be obtained without undue discomfort or upset. The value of balanced information and establishing an early rapport with the child and parents cannot be overstated.

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