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Objective Assessment of Tactile Sensitivity Using Conventional and EEG-Based Measures: A Review

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Abstract: Tactile sensitivity is an important component of the somatosensory system and contributes to motor control, balance, and functional independence. Impairment of tactile function is commonly observed in aging populations and in neurological or metabolic disorders, making accurate assessment clinically important. This review summarizes the neurophysiological basis of tactile perception and examines commonly used assessment methods, including mechanical tests, electrical stimulation-based techniques, and quantitative sensory testing. Their limitations are also discussed, particularly the dependence on subjective responses, limited ecological validity, and limited sensitivity to subtle sensory changes. Electroencephalography (EEG)-based measures, such as somatosensory evoked potentials (SEPs) and event-related potentials (ERPs), are also discussed as objective tools for assessing somatosensory processing. Overall, current evidence points to a critical gap in the objective and high-resolution evaluation of tactile sensitivity, highlighting the need for more precise, physiologically relevant assessment approaches.

Keywords: Tactile sensitivity; Sensory assessment; Peripheral neuropathy; EEG; Somatosensory processing

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1. Introduction

Tactile perception is a major component of the somatosensory system. It allows individuals to detect, discriminate, and respond to mechanical interactions with the external environment. It plays an essential role in motor control, object manipulation, and postural stability. In particular, plantar tactile input contributes substantially to balance regulation, and its impairment has been linked to an increased risk of falls, especially in older adults. Previous studies have shown that reduced plantar sensitivity is associated with impaired gait stability and increased fall risk in elderly populations [1,2].

Tactile dysfunction is also seen in various neurological and metabolic disorders. Diabetic peripheral

neuropathy (DPN) is a common example, affecting an estimated 30–50% of individuals with diabetes [3]. Sensory deficits in DPN usually begin in distal regions and are characterized by reduced pressure and vibration perception, which can lead to foot ulceration and an elevated risk of amputation [4]. Similarly, age-related declines in tactile sensitivity have been widely documented, with evidence suggesting progressive deterioration in mechanoreceptor density and peripheral nerve function [5]. These impairments can affect functional independence and quality of life, which makes reliable assessment of tactile function clinically important.

Despite its clinical relevance, quantitative evaluation of tactile sensitivity remains difficult. Conventional methods, including the Semmes–Weinstein monofilament test (SWMT) and two-point discrimination, are widely used because of their simplicity and low cost. For instance, the 10 g monofilament is commonly employed as a clinical threshold for protective sensation in neuropathy screening [6]. However, these methods depend heavily on examiner technique and subjective patient responses, resulting in variability and limited reproducibility [7,8]. In addition, their ability to detect subtle sensory changes is restricted, particularly in early stages of dysfunction.

Electrical stimulation-based techniques such as current perception threshold (CPT) testing have been introduced. By varying stimulation frequency, typically 5 Hz, 250 Hz, and 2000 Hz, CPT has been used to assess the functional status of C, Aδ, and Aβ fibers, respectively [9]. Although CPT provides a relatively standardized threshold measure, electrical stimulation does not fully reproduce natural mechanical tactile input and may therefore have limited ecological validity for evaluating everyday somatosensory function [10].

More recently, neurophysiological approaches, particularly electroencephalography (EEG), have been increasingly used to examine somatosensory processing. Somatosensory evoked potentials (SEPs) and event-related potentials (ERPs) provide high temporal resolution and allow detailed investigation of neural responses to sensory stimuli. For example, the N20 component after median nerve stimulation is generally considered an early cortical response related to the primary somatosensory cortex [11]. In contrast, later components such as the P300 are associated with attention-dependent cognitive processing and stimulus evaluation [12]. Previous studies have also shown that SEP amplitude and latency are modulated by stimulus intensity, indicating a close relationship between physical stimulus properties and neural responses [13].

However, most neurophysiological studies have focused on relatively strong or easily detectable stimuli, often using electrical stimulation paradigms. As a result, the neural mechanisms underlying fine tactile discrimination remain insufficiently understood. In particular, responses to subtle variations in tactile input near perceptual thresholds have received limited attention. This gap limits the development of sensitive and objective methods for early detection of sensory dysfunction.

Overall, existing approaches to tactile assessment remain limited by subjectivity, restricted precision, and insufficient ecological validity. There is a clear need for methodologies capable of providing objective and high-resolution quantification of tactile sensitivity. Accordingly, this review aims to summarize the neurophysiological basis of tactile perception, evaluate current assessment methods, and identify key limitations and research gaps to inform the development of more precise and clinically relevant evaluation strategies.

2. Neurophysiological basis and measurement targets of tactile perception

Tactile assessment is not limited to determining whether a stimulus is detected. It also requires an understanding of how mechanical input is encoded and processed within the somatosensory system. Mechanical deformation of the skin is detected by cutaneous mechanoreceptors, mainly Merkel cell complexes, Meissner corpuscles, Pacinian corpuscles, and Ruffini endings [14,15]. These receptors respond to

different features of touch, including sustained pressure, dynamic skin deformation, vibration, and stretch [15]. Signals related to discriminative touch are transmitted mainly through large myelinated Aβ afferent fibers and conveyed through ascending somatosensory pathways to the thalamus and somatosensory cortex [16].

For this reason, tactile test results should be interpreted as reflecting multiple stages of processing, rather than a single peripheral event. Perceptual threshold is one of the most commonly used outcomes in tactile evaluation and is usually defined as the minimum stimulus intensity required for conscious detection. However, threshold values are influenced not only by sensory function but also by attention, cooperation, and response criteria, especially in psychophysical tests [17,18]. This issue becomes particularly important near the detection threshold, where small changes in stimulus intensity may determine whether a stimulus is perceived. Because early sensory decline may first appear as subtle changes in threshold or discrimination ability, methods with higher measurement resolution are needed.

The type of stimulus also affects what is being evaluated. Mechanical stimulation is closer to natural touch because it activates cutaneous receptors through actual deformation of the skin. Electrical stimulation, by contrast, is easier to control and is commonly used in current perception threshold testing and SEP studies [9]. However, it bypasses normal mechanotransduction and may evoke neural responses that differ from those produced by natural tactile input [10]. This distinction is important when the aim is to evaluate tactile function in daily life rather than nerve excitability alone.

EEG-based measures provide another level of information by recording time-locked neural responses during somatosensory processing. Early SEP components and later ERP components have been used to examine different stages of tactile processing, from early cortical responses to attention-related stimulus evaluation [11,12]. In addition, previous studies have shown that SEP responses can vary with stimulus intensity, suggesting that EEG measures may provide objective information about changes in sensory input [13].

In practice, however, stable EEG responses have often been obtained using electrical stimulation or clearly suprathreshold stimuli. Less is known about how the brain responds to small, naturalistic tactile changes near individual perceptual thresholds. Combining precise mechanical stimulation with EEG measures may therefore provide a useful direction for evaluating fine tactile sensitivity.

Figure 1 summarizes the relationship between tactile information processing and measurable assessment outcomes, including behavioral responses and EEG-based indicators.

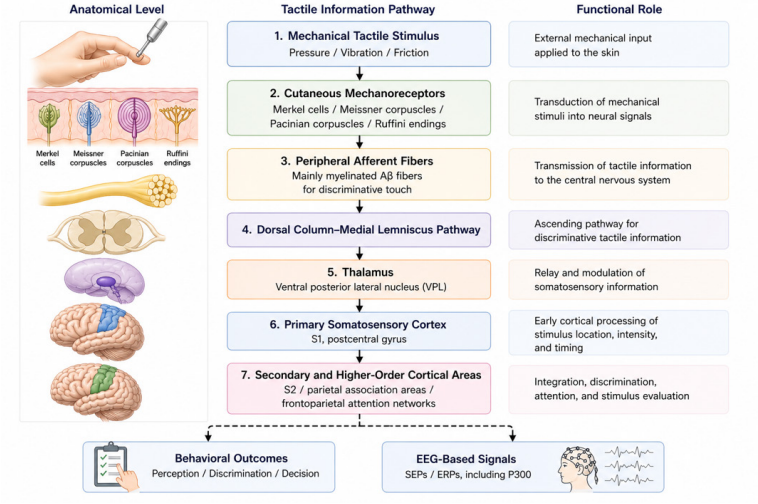

Figure 1. Framework of tactile information processing and objective assessment.

Mechanical tactile stimuli are detected by cutaneous mechanoreceptors and transmitted mainly through myelinated Aβ afferent fibers and the dorsal column–medial lemniscus pathway to the thalamus and primary somatosensory cortex (S1). The information is then further processed in the secondary somatosensory cortex (S2) and higher-order cortical areas involved in discrimination, attention, and stimulus evaluation. Tactile processing can be assessed through behavioral outcomes, such as perception and discrimination, as well as EEG-based signals, including somatosensory evoked potentials (SEPs) and event-related potentials (ERPs), particularly the P300 component.

3. Conventional assessment methods

A variety of methods have been used to assess tactile sensitivity in clinical and research settings. These methods differ in the type of stimulus applied, the sensory function evaluated, and the level of quantification provided. Conventional approaches can be broadly divided into mechanical stimulation-based tests, electrical stimulation-based tests, and standardized quantitative sensory testing protocols.

3.1. Semmes–Weinstein monofilament test (SWMT)

The SWMT is one of the most widely used clinical tools for assessing pressure perception. It uses nylon filaments that bend when a specific force is applied to the skin. In clinical screening for diabetic peripheral neuropathy, the 10 g monofilament is commonly used to evaluate protective sensation, especially on the plantar surface of the foot [6–8].

During testing, the filament is usually applied perpendicular to the skin until it bends, and the participant is asked to report whether the stimulus is felt. The method is simple, inexpensive, and easy to perform at the bedside. For this reason, it remains a practical screening tool in many clinical settings. The outcome is usually based on whether the participant can detect a limited number of filament forces, so the result is often relatively coarse.

3.2. Two-point discrimination test

The two-point discrimination test is used to evaluate tactile spatial acuity. It measures the minimum distance at which two simultaneously applied points are perceived as two separate stimuli rather than one [19]. This method is commonly used for assessing sensory function in the hand and other body regions where spatial resolution is clinically relevant.

Threshold values vary markedly across body sites. Fingertips generally show much lower thresholds than the lower limbs because of their higher receptor density and larger cortical representation. The test is useful for evaluating spatial discrimination, but the measured threshold can be affected by the pressure applied, the shape of the testing instrument, and the participant's response criterion. Therefore, it is best understood as a practical clinical measure of tactile spatial acuity rather than a highly precise quantitative method.

3.3. Vibration perception test

Vibration perception testing is commonly used to evaluate vibrotactile sensitivity and large-fiber sensory function. Vibration and touch sensation tests have been used to assess plantar sensory decline in older adults [2]. In clinical practice, vibration perception is commonly examined using a tuning fork or quantitative vibration

devices, and the participant reports whether vibration is perceived.

More quantitative approaches use devices such as biothesiometers or vibration threshold meters, which allow vibration amplitude to be adjusted and vibration perception threshold to be estimated. Compared with a tuning fork, these devices provide more graded information. However, vibration perception testing still depends on subjective detection and can be influenced by attention, instruction, and testing conditions. It mainly reflects large-fiber function and does not fully capture other aspects of tactile perception, such as spatial discrimination or dynamic friction-based touch.

3.4. Current perception threshold testing (CPT)

CPT testing is an electrical stimulation-based method used to evaluate sensory nerve function. It applies sinusoidal electrical stimulation at different frequencies, commonly 2000 Hz, 250 Hz, and 5 Hz. These frequencies have been used to assess the functional status of Aβ, Aδ, and C fibers, respectively [9].

In CPT testing, the electrical current is gradually adjusted, and the participant reports when the stimulus becomes detectable. Compared with simple mechanical screening tools, CPT provides a more standardized stimulus and allows frequency-specific evaluation of sensory nerve function. It has therefore been used in the assessment of peripheral neuropathy and other sensory disorders. However, because the stimulus is electrical rather than mechanical, CPT assesses nerve excitability more directly than natural tactile perception.

3.5. Quantitative sensory testing (QST)

QST refers to a group of standardized psychophysical methods used to evaluate somatosensory function. Depending on the protocol, QST can assess mechanical detection thresholds, mechanical pain thresholds, vibration detection thresholds, thermal detection thresholds, and pressure pain thresholds [17,18]. The German Research Network on Neuropathic Pain protocol is one of the best-known standardized QST protocols and provides reference values for different sensory parameters [18].

3.6. Summary of conventional methods

Conventional tactile assessment methods provide useful information about different aspects of somatosensory function. The SWMT mainly evaluates pressure detection and protective sensation. Two-point discrimination assesses spatial acuity. Vibration perception testing reflects vibrotactile and large-fiber function. CPT provides frequency-specific electrical threshold information. QST offers a broader standardized framework for assessing multiple sensory modalities.

These methods remain important because they are clinically accessible and relatively easy to administer. However, they measure different components of tactile function and should not be interpreted as interchangeable. Their main characteristics are summarized in **Table 1**.

Table 1. Comparison of conventional tactile assessment methods

Method	Stimulus type	Main measurement	Clinical use
Semmes–Weinstein monofilament test	Mechanical pressure	Pressure detection / protective sensation	Diabetic neuropathy screening
Two-point discrimination test	Mechanical contact	Spatial tactile acuity	Hand sensory assessment

Vibration perception test	Mechanical vibration	Vibration detection threshold	Large-fiber sensory assessment
Current perception threshold testing	Electrical stimulation	Current perception threshold	Sensory nerve function assessment
Quantitative sensory testing	Mechanical/thermal/vibratory stimuli	Multiple sensory thresholds	Sensory profiling

4. Limitations of current tactile assessment methods

Although conventional tactile assessment methods are widely used in both clinical and research settings, each method captures only part of somatosensory function. Bedside mechanical tests, electrical stimulation-based methods, and QST all provide useful information, but they also have limitations. These limitations are mainly related to subjective responses, measurement resolution, ecological validity, and the detection of subtle sensory changes.

4.1. Dependence on subjective responses

Most tactile assessment methods require participants to report whether a stimulus is perceived. This applies to bedside tests such as the Semmes–Weinstein monofilament test, two-point discrimination, vibration perception testing, and also to more standardized methods such as CPT and QST. As a result, threshold values may be influenced not only by sensory function, but also by attention, understanding of instructions, fatigue, and response criteria [17,18].

Examiner-related factors can also affect the results. In monofilament testing, for example, the force, duration, and angle of application may vary across examiners. Systematic reviews have reported variability in the diagnostic performance of monofilament testing for peripheral neuropathy, suggesting that the results should be interpreted carefully when used as a single screening tool [7,8].

4.2. Limited measurement resolution

Many commonly used bedside tests provide relatively coarse or categorical outcomes. The SWMT, for example, usually evaluates whether a limited set of filament forces can be detected. Two-point discrimination provides a spatial threshold, but the result can be affected by the testing instrument, pressure applied to the skin, and participant response strategy [19].

This limitation becomes more important when the aim is to detect small changes in tactile sensitivity. Conventional clinical tests are useful for identifying clear sensory loss, but they may not be sensitive enough to capture gradual or fine-scale changes. QST provides more detailed sensory profiling than simple bedside tests, but it remains a psychophysical method and still depends on participant responses [17,18].

4.3. Limited ecological validity of electrical stimulation

Electrical stimulation-based methods provide well-controlled stimulus timing and intensity. CPT, for instance, uses sinusoidal electrical stimulation at different frequencies to evaluate sensory nerve function [9]. This is useful for assessing nerve excitability, but electrical stimulation bypasses normal mechanical deformation of the skin and cutaneous mechanotransduction.

This distinction is important because natural tactile perception usually arises from mechanical interactions with the skin, including pressure, vibration, friction, and skin deformation. Recent evidence

suggests that electrical and tactile stimulation may involve different neural mechanisms of perception [10]. Therefore, results obtained from electrical stimulation should not be assumed to represent everyday tactile processing fully.

4.4. Limited sensitivity to early or subtle sensory changes

Another challenge is the detection of early or subtle sensory changes. In diabetic peripheral neuropathy and aging-related sensory decline, tactile and vibration perception are commonly affected, and subtle sensory changes may be clinically relevant before severe functional loss becomes apparent [2–5]. However, many commonly used screening methods are designed mainly to identify clinically apparent deficits rather than small variations near perceptual thresholds.

This point is particularly relevant for research on fine tactile discrimination. Near the detection threshold, small differences in stimulus intensity may alter perception, reaction time, or neural responses. Current clinical tools are useful for routine assessment, but they are not always sufficient for quantifying these small changes with high resolution.

4.5. Summary of critical gaps

Overall, current tactile assessment methods remain clinically useful, but they are not interchangeable and should be interpreted according to what each method measures. Mechanical bedside tests are simple and accessible, but they often provide response-dependent and relatively coarse outcomes. Electrical methods offer controlled stimulation, but they may not fully reflect natural mechanical touch. QST provides a more systematic sensory profile, yet it remains psychophysical.

These limitations do not reduce the value of existing methods. Rather, they indicate the need for complementary approaches that can link precisely controlled tactile stimulation with objective neurophysiological responses. In particular, methods that examine fine mechanical variations near individual perceptual thresholds may help clarify how subtle tactile inputs are represented in the nervous system.

5. EEG-based neurophysiological approaches

EEG-based neurophysiological methods provide a complementary way to examine tactile processing. Unlike conventional behavioral tests, EEG can record neural responses to sensory input with high temporal resolution. This makes it useful for studying both early sensory processing and later cognitive evaluation of tactile stimuli.

5.1. Somatosensory evoked potentials (SEPs)

SEPs are time-locked neural responses elicited by peripheral sensory stimulation. They are widely used to assess the functional integrity of somatosensory pathways in both clinical and research settings [20]. In standard SEP recordings, electrical stimulation is often applied to peripheral nerves, such as the median nerve or posterior tibial nerve, and the resulting cortical responses are analyzed by latency and amplitude.

SEP components provide information about different stages of somatosensory processing. Early cortical components, such as the N20 after median nerve stimulation, are commonly used to evaluate early cortical somatosensory processing. Latency reflects the timing of sensory transmission and cortical activation, whereas amplitude reflects the strength of the evoked response [20]. These features make SEPs useful

indicators for examining how sensory input is processed in the nervous system.

5.2. ERP and P300 responses in tactile tasks

In addition to early SEP responses, EEG can also capture later stages of tactile processing through event-related potentials (ERPs). The P300 component is particularly relevant because it is associated with attention, stimulus discrimination, and stimulus evaluation. In somatosensory discrimination tasks, P300 responses have been observed when participants are required to detect or distinguish target stimuli [21].

For tactile assessment, P300 measures are useful because they reflect more than simple stimulus detection. P300 amplitude is generally related to the amount of attentional resources allocated to the stimulus, while P300 latency is often interpreted as reflecting the time required for stimulus evaluation. Therefore, P300 may provide information about perceptual and cognitive processing that is not captured by threshold-based behavioral tests alone.

5.3. Effects of stimulus intensity on EEG responses

One important advantage of EEG-based assessment is that it can be used to examine how physical changes in sensory input are reflected in neural activity. Previous SEP research has shown that stimulus intensity can influence both latency and amplitude of short-latency somatosensory responses [13]. In general, stronger stimulation tends to produce more robust evoked responses, making it easier to obtain stable EEG signals.

However, this also creates a methodological limitation. Many SEP studies have used electrical stimulation or clearly detectable suprathreshold stimuli because these conditions produce stable and reproducible responses. While useful for clinical neurophysiology, such paradigms may not fully explain how the brain processes subtle mechanical tactile changes. This is particularly important when the research focus is fine tactile discrimination rather than gross sensory pathway function.

5.4. Near-threshold tactile EEG and MEG studies

Near-threshold tactile stimulation is especially relevant for understanding fine sensory processing. Earlier EEG work showed that tactile stimuli at the detection threshold can elicit somatosensory evoked potentials, suggesting that threshold-level tactile processing can be studied neurophysiologically [22]. This finding is important because it indicates that weak tactile inputs can produce measurable cortical responses.

Later MEG studies further examined cortical processing of near-threshold tactile stimuli. Wühle and colleagues investigated near-threshold tactile processing and showed that weak tactile stimuli can influence cortical responses, although the direct responses are often small and difficult to detect [23,24]. These studies suggest that the brain may process subtle tactile inputs even when they are close to the perceptual limit.

At the same time, the number of studies in this area remains limited. Near-threshold stimulation is methodologically challenging because the neural responses are weak, detection is variable, and many trials may be required to obtain reliable signals. As a result, the relationship between fine-scale mechanical tactile variations and EEG responses is still not well established.

5.5. Existing gap

Overall, EEG-based approaches provide useful information about both early sensory encoding and later cognitive processing. SEPs can be used to evaluate early cortical responses, while ERPs such as the P300 can reflect attention and stimulus evaluation. These measures may complement conventional sensory tests by

adding objective information about neural processing.

A remaining gap is the limited understanding of how small mechanical changes in tactile input are reflected in EEG responses, especially near individual perceptual thresholds. Although previous studies have provided important evidence, many have relied on electrical stimulation, suprathreshold stimuli, or indirect paradigms. Combining precisely controlled mechanical tactile stimulation with EEG-based measurement may help clarify how subtle tactile inputs are processed. The main EEG-based measures relevant to tactile assessment are summarized in **Table 2**.

Table 2. EEG-based neurophysiological measures used in tactile assessment

Measure	Main response	Interpretation	Relevance
SEP	N20 / P37	Early cortical somatosensory processing	Evaluates early sensory pathway responses
SEP	Latency and amplitude changes	Sensitivity to stimulus intensity	Links physical stimulus properties with neural responses
ERP	P300	Attention and stimulus evaluation	Evaluates higher-order tactile processing
EEG/MEG	Near-threshold responses	Weak responses to subtle tactile input	Supports fine tactile processing research

6. Discussion

This review summarized conventional tactile assessment methods and EEG-based approaches for evaluating tactile sensitivity. Existing methods remain useful, but each method has a limited scope. Bedside tests such as the Semmes–Weinstein monofilament test, two-point discrimination, and vibration perception testing are simple and clinically accessible. However, they depend on participant responses and often provide relatively coarse outcomes. Electrical stimulation-based methods, such as CPT, allow better control of stimulus parameters, but they do not fully reproduce natural mechanical touch. QST provides a more systematic sensory profile, although it remains a psychophysical method.

A promising direction is the combination of precise mechanical stimulation with neurophysiological recording. Mechanical stimulation is important because it preserves skin deformation and cutaneous mechanotransduction, which are essential features of natural touch. If stimulus intensity can be controlled with high precision, small changes in tactile input can be examined more systematically than with conventional bedside tools.

EEG may add further value by linking controlled tactile input to objective neural responses. SEP latency and amplitude can provide information about early sensory processing, whereas P300 measures may reflect attention and stimulus evaluation. Combining these EEG measures with behavioral outcomes, such as detection accuracy and reaction time, may provide a more complete picture of tactile processing.

The research gap and a possible future framework for objective tactile assessment are summarized in **Figure 2**.

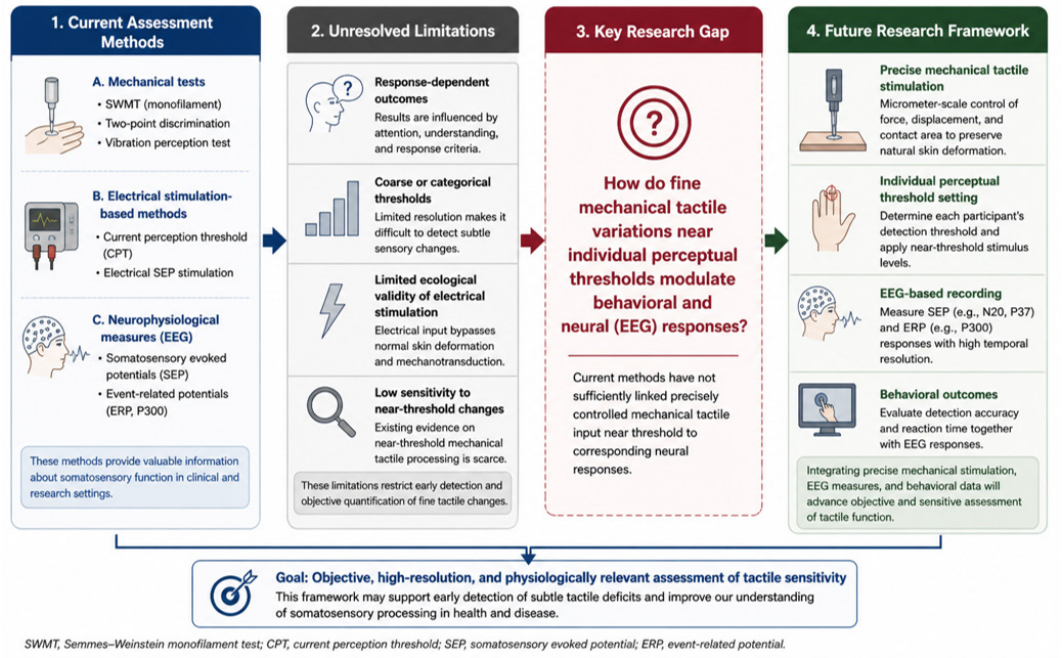

Figure 2. Research gap and future framework for objective tactile assessment.

Current tactile assessment methods include bedside mechanical tests, electrical stimulation-based methods, QST, and EEG-based measures. Although these methods are useful, limitations remain in subjectivity, measurement resolution, ecological validity, and near-threshold sensitivity. A key gap is how fine mechanical tactile changes near individual perceptual thresholds are reflected in behavioral and EEG responses. Future studies may address this gap by combining precise mechanical stimulation, individualized threshold settings, EEG measures such as SEP and P300, and behavioral outcomes such as detection accuracy and reaction time.

Particular attention should be given to near-threshold tactile stimulation. Near the perceptual threshold, small changes in stimulus intensity can produce measurable shifts in perception and neural responses. This range is also important for studying early or subtle sensory changes. However, near-threshold EEG research is technically demanding because responses are weak and easily contaminated by noise. Future studies should therefore prioritize careful stimulus control, sufficient trial numbers, artifact reduction, and individualized threshold settings.

At this stage, such approaches should be regarded as complementary to existing clinical tests rather than replacements. Their immediate value may lie in improving the understanding of fine tactile processing. In the longer term, integrated methods that combine precise mechanical stimulation with EEG may contribute to the development of more sensitive tools for evaluating somatosensory function in aging and peripheral neuropathy.

7. Conclusion

Tactile sensitivity is an important component of somatosensory function and contributes to movement, balance, object manipulation, and daily activities. Conventional assessment methods, including monofilament testing, two-point discrimination, vibration perception testing, CPT, and QST, provide useful information

about different aspects of tactile function. However, these methods are limited by subjective responses, relatively coarse measurement resolution, and, in the case of electrical stimulation, reduced ecological validity for natural touch.

EEG-based methods offer a complementary approach by recording neural responses to sensory input. SEPs provide information about early cortical processing, while ERPs such as the P300 reflect later attention-related and evaluative processes. Previous studies indicate that EEG responses are sensitive to stimulus intensity and that near-threshold tactile processing can be examined neurophysiologically. Nevertheless, the neural processing of fine mechanical tactile changes near perceptual thresholds remains insufficiently understood.

Future tactile assessment research should move toward integrated approaches that combine precise mechanical stimulation with EEG-based neurophysiological measurement. Such approaches may help clarify how subtle tactile inputs are encoded and evaluated by the nervous system, and may provide a foundation for more objective and sensitive assessment of somatosensory function.

Disclosure statement

The authors declare no conflict of interest.

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