ORIGINAL ARTICLE

Evaluating Neurological Outcomes in Neonates Through SSEP: A Review of Current Evidence

J of Neurophysiological Monitoring 2025; 3(3): 9-20 ISSN 2995-4886

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KEYWORDS: Somatosensory evoked potentials, neonatal neurology, cerebral palsy, intraoperative monitoring, neurodevelopment, ECMO, BAEP, MEP, EEG

CITE AS: Siddiqui ER, Ayyoub SM, , Parapperi R, Isa UJ, Mohammed J, Habib SM, Memon, U, Jahangiri FR. Evaluating Neurological Outcomes in Neonates Through SSEP: A Review of Current Evidence. J of Neurophysiological Monitoring 2025; 3(3): 9-20. doi:10.5281/zenodo.16923257

ARTICLE HISTORY:
Received: May 23, 2025
Accepted: Aug 14, 2025
Available online: Aug 21, 2025

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ABSTRACT

Somatosensory evoked potentials (SSEPs) are increasingly recognized as valuable tools for assessing neurological function, maturation, and prognostic outcomes in neonatal populations. This systematic review evaluates the efficacy and practicality of SSEPs in preterm infants (less than 32 weeks of gestation) and full-term infants up to 6 months of age.

Findings indicate that SSEPs provide reliable biomarkers for neural development and predictive indicators for conditions such as cerebral palsy (CP). Posterior tibial SSEP recordings demonstrated a positive predictive value of 83% for CP, outperforming cerebral ultrasound and visual evoked potentials (VEPs). SSEPs also show clinical relevance in intraoperative neurophysiological monitoring (IONM), particularly during procedures involving extracorporeal membrane oxygenation (ECMO).

Despite promising results, limitations persist, including small sample sizes, lack of longitudinal follow-up, and variability in recording protocols. Factors such as anesthesia response, physiological state, and gestational age contribute to inconsistencies. Future research should prioritize protocol standardization and multimodal integration with brainstem auditory evoked potentials (BAEPs), motor evoked potentials (MEPs), and electroencephalography (EEG). Longitudinal studies are essential to assess the enduring impact of early SSEP findings on neurodevelopmental trajectories. Establishing SSEPs as a routine diagnostic tool may enhance early intervention strategies and improve outcomes for at-risk neonatal populations.

INTRODUCTION

The neonatal period is a crucial time for neurological development, especially in preterm infants whose central nervous systems are rapidly and complexly maturing. Early identification of neurological dysfunction in this population is vital for guiding timely interventions, optimizing developmental outcomes, and informing long-term care strategies. However, conventional diagnostic tools, such as neuroimaging and clinical examinations, often struggle to detect subtle or evolving abnormalities, particularly in sedated or critically ill neonates. This diagnostic gap has led to increased interest in neurophysiological methods that provide objective, real-time insights into brain function.

Somatosensory evoked potentials (SSEPs) present considerable potential for assessing real-time neurological function, development, and long-term outcomes in neonatal patients. To further establish the importance of this approach, this literature review evaluates the practicality and efficacy of SSEPs in preterm infants (less than 32 weeks of gestation) and full-term infants up to 6 months of age. Between December 2024 and February 2025, we conducted a systematic search using databases such as PubMed, ScienceDirect, the Cochrane Library, and Google Scholar. The inclusion criteria focused on studies that recorded and analyzed SSEP data in neonates, specifically targeting functional assessments and changes in patient outcomes. Studies involving animal research, adults, older children, or any populations outside of the neonatal period were excluded.

Research findings indicate that SSEP recording in neonates provides reliable measurements for neural maturation and has strong predictive power for neurological outcomes, such as cerebral palsy (CP). For example, posterior tibial SSEPs demonstrated a positive predictive value of 83% for detecting CP, outperforming both cerebral ultrasound and visual evoked potentials (VEPs). Furthermore, SSEPs have proven beneficial in intraoperative neurophysiological monitoring (IONM) in clinical settings, particularly for early detection of neurological complications during procedures like extracorporeal membrane oxygenation (ECMO) and other neurosurgeries.

The review identifies several gaps in the current literature that require further research, such as limitations regarding sample sizes, the lack of follow-up studies, and inconsistencies in recording conditions. Additionally, challenges remain in standardizing SSEP protocols due to variability in responses influenced by factors like anesthesia, the patient's physiological state, and gestational age. Future research should focus on integrating SSEPs with other neurophysiological modalities, including brainstem auditory evoked potentials (BAEPs), motor evoked potentials (MEPs), and electroencephalography (EEG). Moreover, longitudinal studies are needed to investigate the long-term impacts of early SSEP findings on neurodevelopment. By addressing these limitations, we can work towards making SSEPs a routine component of neonatal care, optimizing interventions, improving early diagnoses, and ultimately enhancing outcomes for pre-term infants.

METHODOLOGY

For this literature review, we searched publicly available articles in the following databases: PubMed, ScienceDirect, Cochrane Library, and Google Scholar, from December 2024 to February 2025, regarding the efficacy and practicality of SSEPs in neonates. Additionally, several articles that were not publicly accessible were obtained through the University of Texas at Dallas (UTD) library resources to ensure a comprehensive review of the available literature. Keywords used for the literature search were neonates, infants, somatosensory evoked potentials, and SSEPs. The inclusion criteria consisted of: (1) neonates born preterm from <32 weeks of gestation, to infants aged 6 months, (2) cases where SSEPs were successfully recorded, (3) included data analyzing changes in outcomes or functions compared to baseline i.e. SSEP readings were recorded and reported, (4) individuals that did have a pre-existing neurological condition. There was no restriction set on the date of the published studies for inclusion. Excluded were case studies, which were studies conducted in children, adolescents, adults, and the geriatric population. Publications that did not include information about SSEP recordings in neonates, and studies that were closed access and not retrievable, were also excluded. No patient data was involved, and no informed consent or approval of an Institutional Review Board was required for this study.

Outcomes:

SSEPs have been successfully recorded in neonates, including preterm infants, with studies supporting their feasibility in both intraoperative and non-surgical monitoring. Abnormal SSEP findings have been associated with poor neurological outcomes, such as cerebral palsy, coma, and even death. Sensitivity and specificity values reported for Posterior Tibial Nerve (PTN) SSEP in predicting cerebral palsy were 62.5% and 99%, respectively [1]. These findings suggest SSEP can serve as a predictive tool for long-term neuromotor outcomes in high-risk neonatal populations.

Recording Setup:

Cortical somatosensory evoked potentials (SSEP) are recorded using scalp electrodes placed according to the international 10-20 system, which standardizes placement for accurate signal acquisition. Bandpass filters typically optimized for evoked potential detection operate within the 30 Hz to 1000 Hz range, effectively isolating physiological signals from background noise.

Although sweep times can vary, they are usually around 100 milliseconds (ms) for protocols involving neonates and infants, ensuring that responses are accurately captured. Adhering to these established practices leads to more reliable monitoring and assessments of neural function.

Stimulation Setup:

Stimulation is delivered to the posterior tibial nerve located at the medial aspect of the ankle through the application of electrical pulses. The stimulation intensities are calibrated to be at or above the supra-motor threshold, ensuring effective nerve activation. The pulse widths utilized in these procedures typically range from 100 to 500 microseconds, allowing for flexibility in the response characteristics of the nerve stimulation. The maximum intensity can reach up to 14 mA, which is critical for achieving the desired therapeutic effects. In various studies, the most frequently employed repetition rate is 0.5 Hz; however, alternative rates of 1 Hz and 5 Hz are also implemented depending on the specific research context and objectives, allowing for tailored approaches to nerve stimulation based on individual patient needs or study requirements.

RESULTS

Feasibility of SSEP Recording in Neonates

Across the reviewed literature, SSEPs were successfully recorded in both preterm (<32 weeks of gestation) and full-term neonates. Studies consistently demonstrated the technical feasibility of capturing cortical responses using scalp electrodes, with stimulation typically applied to the posterior tibial nerve. Despite variability in electrode placement and filter parameters, standard protocols, such as bandpass filtering between 30–1000 Hz and sweep times around 100 ms, enabled reproducible recordings in neonatal populations.

Predictive Value for Neurological Outcomes

Somatosensory evoked potentials (SSEPs) have demonstrated significant predictive capability for neuromotor abnormalities, especially cerebral palsy (CP). In a study by Pike et al. (2000), posterior tibial SSEPs achieved a positive predictive value (PPV) of 83% for CP, along with sensitivity and specificity rates of 62.5% and 99%, respectively [1]. These findings are markedly better than those from cerebral ultrasound, which has a PPV of only 17%, and flash visual evoked potentials (FVEP), which has a PPV of 38%. This positions SSEPs as a superior method for early risk stratification in detecting CP.

Real-Time Monitoring During Critical Care

SSEPs were effectively utilized in intraoperative and intensive care settings. McDevitt et al. (2023) demonstrated successful implementation of SSEP alongside EEG and near-infrared spectroscopy (NIRS) during extracorporeal membrane oxygenation (ECMO), achieving a 76% completion rate across 42 planned sessions [2]. Abnormal SSEP findings correlated with significant neuroradiological abnormalities, including subdural and intraventricular hemorrhage. Shalita et al. (2022) further validated SSEP's intraoperative utility during thoracic dermal sinus tract resection, identifying iatrogenic injury in real time [3].

Developmental Insights and Neurophysiological Maturation

Studies by Gilmore et al. (1987) and Zhu et al. (1987) provided normative latency data for cortical SSEP components, demonstrating consistent developmental shortening of waveform latencies with increasing gestational age [4]. Khedr et al. (2004) revealed that breastfed infants exhibited more mature neurophysiological responses compared to formula-fed counterparts, as evidenced by prolonged FVEP latencies and increased inter-peak intervals in BAEP recordings [5]. These findings underscore SSEP's sensitivity to subtle differences in neurodevelopment influenced by environmental and nutritional factors.

Limitations in Protocol Consistency

Despite promising results, inconsistencies in stimulation parameters, electrode configurations, and recording conditions were noted across studies. Pulse widths ranged from 100–500 µs, with stimulation intensities up to 14.0 mA and repetition rates varying between 0.5 Hz and 5 Hz. Electrode placements were not uniformly reported, and filter settings varied widely, complicating cross-study comparisons and clinical standardization.

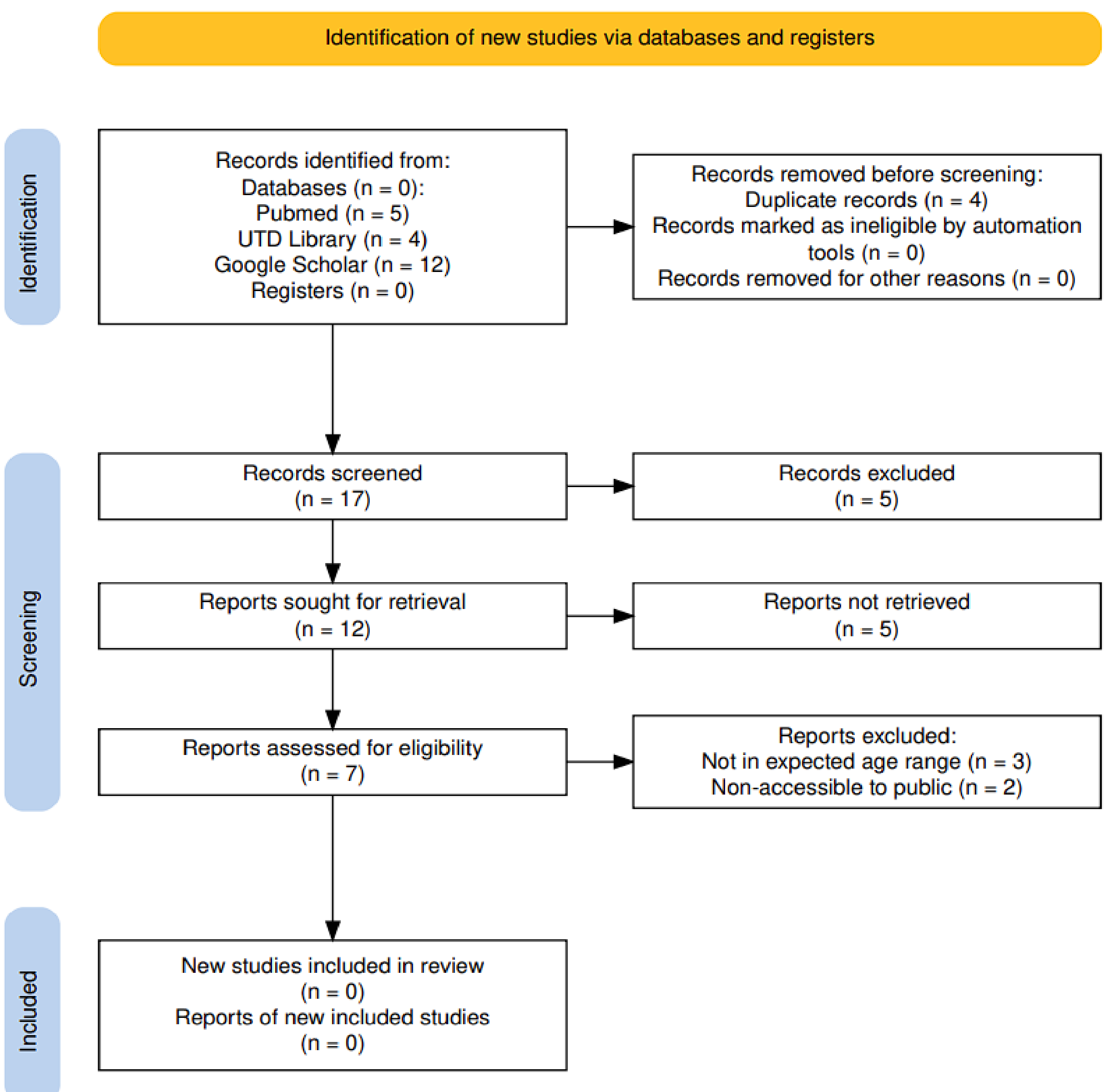

Figure 1. PRISMA flow chart.

Study	Overall Sample Size	Sample size	IONM used
AA Pike et al., 2000	93	93	(PTN-SSEP), VEP
William M McDevitt, et al, 2023	14	14	SSEP , EEG, and NIRS
Marlon N et al,. 1997	67	67	PTN-SSEP
R. Gilmore et al., 1987	29	29	PTN-SSEP
EMH Khedr et al,. 2004	53	53	VEP, BAEP, and (SSEP).
Chidyaonga Shalita et al. 202:	Meta-analysis	Meta-analysis	Multmodality
Bernard Dachy., 2017	Meta-analysis	Meta-analysis	Multmodality

Table 1. List of papers assessed.

DISCUSSION

Foundational Insights on the Efficacy of SSEPs in Neurological Assessment of Preterm Newborns

The utilization of Somatosensory Evoked Potentials (SSEPs) has emerged as a robust method for evaluating neurological development in preterm newborns. This technique involves the electrical stimulation of peripheral nerves, which can include the median or ulnar nerves at the wrist for upper extremity assessments, with alternative stimulation sites such as the superficial radial nerve or Erb's point. For lower extremity evaluations, the tibial nerve at the ankle or the peroneal nerve near the fibular head is targeted.

To facilitate optimal physiological responses, these stimulation protocols apply a constant current at frequencies ranging from 2 to 5 Hz, with pulse durations set between 200 to 300 microseconds. The resultant neural activity is characterized by the generation of the cortical N20 peak, a significant marker within the upper extremity SSEP which typically appears around 20 milliseconds post-stimulation, specifically over the contralateral postcentral gyrus.

Subdermal needle electrodes are strategically placed according to the international 10-20 system at locations such as CP3 and CP4 for upper extremity assessments, and CPz and CPi for lower extremity evaluations. The configuration of filter settings is critical; optimized filters should range from 1-30 Hz to 250-1000 Hz for capturing cortical signals and 30-100 Hz to 1000-3000 Hz for subcortical signals. It is essential to avoid employing a 60 Hz notch filter due to potential signal distortion that could compromise data integrity.

A pivotal study by Gilmore et al. (1987) explored the application of SSEPs in assessing the entire neuraxis in preterm neonates, revealing its efficacy in consistently recording key neurological components, such as the N5 and N16 waves, across a diverse cohort of subjects, irrespective of gestational length [4]. This finding underscores the reliability of SSEPs as a valuable diagnostic tool for measuring neurological function and monitoring developmental responses to nerve stimulation in this vulnerable population.

Further extending the application of SSEPs, research by Khedr et al. (2004) illuminated the interplay between neurodevelopment and nutritional factors, particularly contrasting breastfed versus formula-fed infants [5]. The study demonstrated that breastfed infants exhibited more mature neurophysiological responses, evidenced by increased wave latencies in Flash Visual Evoked Potentials (FVEP) and extended absolute latencies in waves I, III, and V of Brainstem Auditory Evoked Potentials (BAEP). Notably, the research also reported significant inter-peak latency increases between cortical and Erb's components among formula-fed infants. These findings accentuate the sensitivity of SSEPs in detecting subtle variations in neural maturation, further establishing the technique as an essential instrument for evaluating developmental trajectories and interventions in preterm infants.

Real-time Usage:

The real-time application of somatosensory evoked potentials (SSEPs) during surgeries underscores their critical significance in intraoperative neurophysiological monitoring (IONM) and intensive care settings. A notable study conducted by McDevitt et al. (2023) emphasizes the vital role of SSEP in detecting neurological complications in children undergoing extracorporeal membrane oxygenation (ECMO) [2]. ECMO is a sophisticated critical care intervention employing a mechanical circulatory device that takes over the functions of both the heart and lungs. This advanced technique facilitates the essential processes of gas exchange and circulation, oxygenating blood outside the body, making it a lifesaving procedure often utilized for pediatric patients with severe and refractory cardiac or pulmonary dysfunction. Serving as a temporary support mechanism, ECMO is pivotal in helping these young patients recover from critical conditions.

In the McDevitt study, SSEP was adeptly integrated with electroencephalography (EEG) and near-infrared spectroscopy (NIRS), successfully completing 32 out of 42 planned neuro-monitoring sessions, resulting in a commendable completion rate of 76%. The findings revealed that 57% of SSEP tests (8 out of 14 patients) yielded results within normal limits. However, abnormalities were observed in 40% of patients (4 out of 10) who presented with abnormal neuroradiology findings. Further analysis showed that SSEP asymmetries were noted in 29% of the patients (4 out of 14), correlating with significant neurological issues, such as subdural or intraventricular hemorrhage [2]. These outcomes demonstrate SSEP's remarkable capacity for early detection of neurological complications, especially in a pediatric intensive care environment where physical examinations may be constrained due to sedation or the procedural complexities associated with ECMO.

In addition, Shalita et al. (2022) reported on the effective utilization of SSEP in a procedural context involving neonates. In this scenario, SSEP was employed to monitor patients undergoing surgical resection of the dermal sinus tract located at the T4-T6 vertebral levels [3]. This application once again highlighted SSEP's ability to detect iatrogenic injuries in real-time, ensuring prompt intervention when necessary.

Overall, in both studies, SSEP emerged as a crucial tool for monitoring clinical outcomes in the vulnerable pediatric population, reinforcing its importance in safeguarding neurological health during critical medical procedures.

Predictive Power of SSEP:

Somatosensory Evoked Potentials (SSEP) is effective in predicting neuromotor outcomes and evaluating the maturation of neurological pathways in neonates. A study by Pike et al. (2000) highlights the usefulness of posterior tibial SSEP in offering a high predictive value for neuromotor abnormalities [1]. The researchers found that SSEP had an 83% positive predictive value for cerebral palsy and a 100% predictive value for identifying abnormal neurological conditions. In comparison, cerebral ultrasound yielded much lower predictive values, with only 17% for cerebral palsy and 40% for abnormal neurology. Furthermore, Flash Visual Evoked Potentials (FVEP) had a 38% predictive value for cerebral palsy and 85% for abnormal neurology, underscoring the superior efficacy of SSEP in these diagnostic contexts [1].

In another study by Pike et al. (1997), the focus was on the maturation process of SSEP, providing normative data for the peak component waveforms of the posterior tibial SSEP response [6]. They reported that the latency of the first cortical component decreases as maturation progresses, while there is no significant change in waveform morphology with advancing gestational or postnatal age. This developmental pattern is clearly outlined in the normative latency values reported by Zhu et al. (1987), as presented in Table 2 [7]. Together, these studies provide valuable insights into the integrity and functional progression of the nervous systems in high-risk neonatal populations.

Developmental Changes in SSEP Latencies

Normative values from Zhu et al. (1987)

SSEP Component	Parameter	Age Groups		Notes
		Neonates (1d-1m)	Older Children (14y-16y)	
Posterior Tibial (P)[1]	Onset latency (ms)	29.76 ± 2.95	31.62 ± 1.95	*Slower onset in neonates*
	Peak latency (ms)	38.21 ± 4.02	36.54 ± 1.81	*Neonatal delay reflects myelination status*
	Ascending time (ms)	8.54 ± 2.56	4.92 ± 0.85	*Greater temporal dispersion*
Median Nerve (N)[2]	Onset latency (ms)	16.04 ± 1.90	13.82 ± 1.30	*Faster conduction in mature pathways*
	Peak latency (ms)	24.98 ± 2.71	17.15 ± 1.00	*Significant maturation effect*
	Ascending time (ms)	8.94 ± 1.84	3.36 ± 0.47	*Improved signal integration*

[1] Posterior Tibial P-wave equivalent to adult P37

[2] Median Nerve N-wave equivalent to adult N20

Table 2. Summary of the key developmental changes in SSEP latencies, providing normative reference values for clinical interpretation of neonatal physiological data. [Zhu9]. (SSEP: somatosensory evoked potentials). *Created by Salam Ayyoub*.

Future Direction:

The demonstrated effectiveness of SSEP in evaluating neurological development and predicting neuromotor outcomes in neonates highlights its potential for broader applications and improvements. Future research should investigate the integration of SSEP with other modalities such as motor evoked potentials (MEP), visual evoked potentials (VEP), electromyography (EMG), brainstem auditory evoked potentials (BAEP), and electroencephalography (EEG). This multi-modal approach could create a more sensitive and specific diagnostic tool for assessing neonatal neurological health.

Studies could also focus on longitudinal tracking to evaluate the impact of early SSEP assessments on long-term developmental outcomes, potentially establishing SSEP as a standard component of neonatal care protocols, especially for pre-term infants. Furthermore, exploring the effects of nutritional factors is essential, as research has shown differences in neurophysiological responses between breastfed and formula-fed infants. This could lead to personalized nutritional interventions that optimize neurological development.

Importantly, expanding the real-time use of SSEP in surgical and critical care settings, such as during extracorporeal membrane oxygenation (ECMO) or complex neurosurgeries, could enhance protocols to minimize neurological risks and improve patient outcomes. However, this expansion would require rigorous validation of SSEP as a routine monitoring tool in surgery to proactively identify and mitigate potential iatrogenic injuries.

Lastly, the predictive capability of SSEP in identifying risks for conditions like cerebral palsy could be utilized to develop early intervention strategies. Creating predictive models that incorporate SSEP data would enable clinicians to tailor rehabilitation and treatment plans even before clinical symptoms appear.

Gaps in Literature:

The reliability and clinical applicability of SSEP in various patient populations are topics of concern raised by Toleikis et al. (2024) and Dachy (2017). Toleikis et al. (2024) challenge the generalized SSEP warning criteria, such as a 10% increase in latency and a 50% decrease in amplitude, arguing that these standards might not be appropriate for all patients [8]. They advocate for the development of individualized criteria that consider factors such as pre-existing neurological conditions, although they do not provide a detailed analysis of these considerations. Additionally, they underscore the importance of acknowledging variables like anesthesia, temperature fluctuations, and patient-specific characteristics that could impact SSEP results. Toleikis et al. also highlight the lack of clear guidelines for defining SSEP reversibility and stress the need for multimodal monitoring.

Dachy (2017) expands on this issue by discussing the variability in SSEP methodologies and calling for standardized approaches that would lead to more consistent data collection [9]. This study emphasizes how age, developmental stages, and behaviors such as sleep and arousal can influence SSEP responses. Dachy points out that challenges arise when interpreting SSEP data in newborns and patients with hypoxicischemic encephalopathy. Furthermore, the author suggests that the utility of SSEP is limited in cases of milder brain injuries and recommends further research that combines SSEP findings with other imaging modalities.

Research by Khedr et al. (2004) and Gilmore et al. (1987) offers useful insights into infant neurodevelopment; however, these studies face limitations that affect their generalizability [4,5]. Khedr et al. (2004) investigate the impact of breastfeeding versus formula feeding on infant development but are constrained by a small sample size of only 53 infants and a lack of diversity among participants. The study focuses on just three types of evoked potentials without addressing long-term effects or including preterm infants [5]. Similarly, Gilmore et al. (1987) concentrate on preterm infants, but their study suffers from a small participant pool of 29 infants, the absence of a control group, and insufficient long-term data. They also overlook confounding variables such as prenatal exposures and genetic influences, which limit the applicability of their findings [4].

Pike et al. (1997) and McDevitt et al. (2023) investigate neurophysiological monitoring in vulnerable populations, facing comparable obstacles that undermine the reliability of their results. Pike et al. (1997) examine cortical responses in preterm infants but encounter challenges such as a limited sample size, lack of diversity, and absence of longitudinal follow-up, which restricts their ability to assess long-term outcomes [6]. Additionally, inconsistent recording conditions may further complicate data interpretation. McDevitt et al. (2023) deal with recruitment difficulties resulting in small sample sizes that raise concerns about bias [2]. Furthermore, the lack of comprehensive neuroimaging data, combined with missing SSEP, EEG, and NIRS recordings, diminishes the reliability of their findings. The focus on a specific group of ECMO patients with congenital heart defects also compromises the generalizability of the results.

Pike et al. (2000) discuss the broader implications of small sample sizes in studies like those conducted by Pierrat et al. (1997) and Klimach and Cooke (1988), which limit statistical power and relevance [1,10,11]. They express concern about the lack of long-term follow-up, typically confined to 1-2 years, as well as variability in the timing of tests, which can undermine predictive accuracy. Pike et al. advocate for the use of multimodal testing strategies that incorporate SSEP, Visual Evoked Potentials (VEP), and cerebral ultrasound to gain a more comprehensive understanding of neurodevelopmental outcomes. They also highlight challenges such as the labor-intensive nature of SSEP and the high rates of false positives, which can reduce diagnostic reliability [1].

In summary, while the studies reviewed provided valuable insights into SSEP and other neurophysiological monitoring techniques, they all share significant limitations, including small sample sizes, inconsistent methodologies, and insufficient long-term follow-up. These limitations reduce the reliability and applicability of the findings, indicating a pressing need for larger, more diverse cohorts, standardized methodologies, and comprehensive research into neurodevelopmental outcomes.

CONCLUSION

Somatosensory evoked potentials (SSEPs) represent a vital tool in the assessment of neonatal neurological function, providing both predictive insights and real-time monitoring capabilities that are essential for understanding and addressing neurological health in newborns. These techniques allow for the evaluation of the integrity of sensory pathways, which is crucial in identifying potential neurological impairments early in a child's development.

To fully realize the benefits of SSEPs in clinical practice, it is imperative to standardize assessment protocols. This uniformity will ensure that healthcare professionals apply consistent methodologies, enhancing the reliability of results across different clinical settings. Additionally, integrating SSEPs with other diagnostic modalities, such as imaging techniques and clinical examinations, can create a more comprehensive approach to neonatal care, facilitating a multidimensional understanding of a newborn's neurological status.

Ultimately, establishing SSEPs as a routine component of neonatal care promises to improve the early diagnosis of neurological conditions and enhance long-term outcomes for affected infants, guiding timely interventions and therapeutic strategies tailored to their unique needs.

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