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МЕЖДИСЦИПЛИНАРНЫЕ ИССЛЕДОВАНИЯ |

INTERDISCIPLINARY STUDIES

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Neuro-forensic perspectives on childhood bullying: a quantitative EEG (q-EEG) analysis of stress biomarkers in victimized children

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Abstract

Context and relevance. Bullying is a widespread psychosocial problem with serious psychological and neurodevelopmental consequences. Beyond emotional distress, it can affect brain function. Quantitative electroencephalography (q-EEG) enables objective detection of stress-related brain activity, offering potential forensic value. **Objective.** This study examined the impact of bullying-related stress in children by combining behavioral stress assessments with q-EEG analysis. **Hypothesis.** We hypothesized that bullied children would report higher stress levels and exhibit distinct brainwave abnormalities detectable by q-EEG, which could serve as forensic indicators of trauma. **Methods and materials.** Two cross-sectional phases were conducted. In the first, 2,781 Indonesian children (aged 8—13) completed the Perceived Stress Scale (PSS-10) and a bullying questionnaire. In the second, 24 children with high stress indicators underwent clinical q-EEG. Brainwave data across standard frequency bands were analyzed in relation to stress scores. **Results.** 58,3% of children reported being bullied. These children were 2.8 times more likely to experience moderate to severe stress ($p < 0,001$). Among the q-EEG subsample, 95,8% showed cortical abnormalities—reduced bilateral temporal activity (83,3%) and increased prefrontal high-beta waves (29,2%)—linked to emotional dysregulation and anxiety. **Conclusions.** Bullying induces measurable brain changes. q-EEG may serve as a reliable tool for detecting trauma in children, supporting early intervention and forensic child protection.

Keywords: childhood bullying, psychological trauma, neuro-forensics, q-EEG, legal protection

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Маулия Ш.Р., Юдианто А., Ма’руф А., Мачин А. (2026) Нейро-криминалистский подход к изучению буллинга в детском возрасте: количественный ЭЭГ-анализ (q-ЭЭГ) биомаркеров стресса у детей, подвергшихся травле *Психология и право, 16*(2), 244—254.

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Нейро-криминалистский подход к изучению буллинга в детском возрасте: количественный ЭЭГ-анализ (q-ЭЭГ) биомаркеров стресса у детей, подвергшихся травле

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Резюме

Контекст и актуальность. Буллинг представляет собой широко распространенную психосоциальную проблему, имеющую серьезные психологические и нейроразвивающие последствия. Помимо эмоционального дистресса, он может оказывать влияние на функционирование головного мозга. Количественная электроэнцефалография (q-ЭЭГ) позволяет объективно выявлять связанную со стрессом мозговую активность и обладает значительным потенциалом для использования в судебно-экспертной практике. **Цель.** Изучить влияние стресса, обусловленного буллингом, на детей посредством сочетания поведенческой оценки стресса и анализа данных q-ЭЭГ. **Гипотеза.** Предполагалось, что дети, подвергающиеся буллингу, будут демонстрировать более высокий уровень стресса и специфические нарушения мозговой активности, выявляемые с помощью q-ЭЭГ, которые могут рассматриваться как судебно-экспертные индикаторы психической травмы. **Методы и материалы.** Исследование проводилось в два этапа. На первом этапе 2781 ребенок из Индонезии в возрасте от 8 до 13 лет заполнил Шкалу воспринимаемого стресса (PSS-10) и опросник буллинга. На втором этапе 24 ребенка с высокими показателями стресса прошли клиническое обследование методом q-ЭЭГ. Данные о мозговой активности в стандартных частотных диапазонах анализировались в связи с показателями стресса. **Результаты.** О фактах буллинга сообщили 58,3% детей. У этих детей вероятность переживания умеренного или высокого уровня стресса была в 2,8 раза выше ($p < 0,001$). Среди участников, прошедших q-ЭЭГ-обследование, у 95,8% были выявлены корковые нарушения: снижение активности в обеих височных долях (83,3%) и повышение мощности высокочастотных бета-волн в префронтальной коре (29,2%), что связано с эмоциональной дизрегуляцией и тревожностью. **Выводы.** Буллинг вызывает измеримые изменения в функционировании головного мозга. Метод q-ЭЭГ может служить надежным инструментом выявления психической травмы у детей, способствуя раннему вмешательству и совершенствованию мер судебно-правовой защиты детей.

Ключевые слова: буллинг в детском возрасте, психологическая травма, нейро-криминалистика, количественная электроэнцефалография (q-ЭЭГ), правовая защита

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Introduction

Bullying has become a pervasive disease in the educational settings (Gaffney, Ttofi, Farrington, 2021). Bullying impacts not only the victims but also the perpetrators (Montes et al., 2022). Despite increased public awareness, most forensic evaluations still rely heavily on subjective self-reports or caregiver accounts, which may be inconsistent or incomplete (Parmigiani et al., 2023).

The rapid technological advances (in neuroscience) suggest that chronic psychosocial stressors have a profound impact on brain development (Gee, 2021; Mclaughlin, Weissman, Bitrán, 2019). Stressors can have an emotional impact, but their potential to alter brain composition and function is also very high, particularly in areas responsible for emotional regulation, executive function, and memory (Gee, 2021). Repeated bullying has been shown to increase HPA axis activity. Hyperactivity can lead to prolonged cortisol secretion and structural changes in the prefrontal cortex, hippocampus, and amygdala (Mclaughlin, Weissman, Bitrán, 2019). Emotional dysregulation, cognitive impairment, anxiety, and depressive symptoms in children are frequently seen manifestations of neurobiological disorders (Montes et al., 2022; Moore et al., 2017).

The emergence of emotional disorders in emotional regulation, cognition, and behavior is largely shaped by ongoing brain maturation and stress (Langer et al., 2025; Leisman, Alfasi, D'Angiulli, 2025). This is caused by excessive (dramatic) emotional changes during childhood and adolescence, which are complex and multifactorial.

Traditional forensic and clinical evaluations of child trauma often lack the objectivity necessary to detect these subtle but significant neurobiological changes (Parmigiani et al., 2023). Traditional forensics often relies solely on in-depth interviews, observations, or a collection of sentences, which inaccurately capture the abnormalities of internal psychological damage — especially in children who have difficulty expressing the distress they are experiencing. The q-EEG can detect abnormal brainwave activity associated with stress and trauma, offering an objective and reproducible measurement of internal dysfunction (Kopańska et al., 2022). This is why the combination of neurophysiological tools holds great promise for forensics.

The capabilities of q-EEG hold significant potential in identifying emotional dysregulation, anxiety, and hypervigilance in children (Fingelkurts, Fingelkurts, 2022; Livint Popa et al., 2020; Maulia et al., 2026). The combination of clinical and behavioral data can be aided by using q-EEG to identify trauma experienced by children.

Indonesian society still has minimal awareness, and legal mechanisms for addressing the psychological impacts of bullying are also very limited. Furthermore, the use of neuroscience-based evidence in legal or medical child protection systems is still underdeveloped. The complex interactions between neurobiology, psychology, and law, combined with a multidisciplinary approach, result in a study that bridges neurophysiological analysis with a child protection legal framework, aiming to provide empirical support for forensic science standards and policy reform.

There are few such large-scale studies, and we believe ours is one of the first in Indonesia. Ours integrates stress research with q-EEG technology in bullying cases. Our goal, from a neuro-forensic

perspective, is to establish a strong foundation for the application of neuroscience in the child protection system, thereby significantly contributing to efforts to protect children from bullying.

Materials and methods

Participants

This research was divided into two stages:

The first phase involved a large-scale behavioural survey on bullying among school-aged children. A total of 2,781 children aged 8 to 13 years were recruited from eight public and private elementary schools in Surabaya, Indonesia, using stratified cluster sampling.

In the second phase, 24 children who exhibited behavioural indicators of psychological stress based on survey scores were purposively selected for neurophysiological assessment using quantitative EEG (q-EEG). These participants were assessed in a controlled clinical setting under the supervision of licensed clinical neurophysiologists.

Procedure

In the first phase, trained facilitators administered the Perceived Stress Scale (PSS-10) and a bullying behaviour questionnaire to participants in their classrooms using a paper-based format. In the second phase, q-EEG recordings were conducted in a clinical environment. Participants were asked to lie in a resting position with eyes closed during the session to minimize artifacts. Recordings were collected following standard operating procedures for paediatric neurophysiological assessment.

Data Collection

The PSS-10 was used to quantify perceived stress levels, while the bullying questionnaire categorized participants as victims or non-victims. In the second phase, q-EEG data were recorded using a 19-channel system under resting conditions.

Data Analysis

Behavioural data were analysed using SPSS version 26. Logistic regression was used to determine the association between bullying victimization and stress levels. EEG data were analysed for abnormalities in power distribution across delta, theta, alpha, and beta bands, and were statistically correlated with stress scores from the first phase.

Results

Behavioral Results

Table 1 summarizes the behavioural survey findings from the first study phase. Out of 2,781 total students, 1,622 (58,3%) were identified as bullying victims. Among these victims, 1,495 (53,8%) showed signs of moderate to severe stress according to PSS-10 scores. The odds ratio showed that children who were bullied were 2,8 times more likely to experience psychological stress than those who were not victims, which was a statistically significant relationship ($p < 0,001$).

Table 1

Prevalence of bullying victimization and stress levels

Variables	Categories	n	%
Total Students		2,781	100
Bullying	Victims	1,622	58,3

	Non-Victims	1,159	41,7
	Stressed Victims	1,495	53,8
Odds Ratio (Stress)		2,8	(p < 0,001)

Neuropsychological Results

Table 2

Summary of q-EEG abnormalities in stressed children

EEG Finding	Affected Region	n	%	Clinical Interpretation
↓ Power (Temporal lobes)	Bilateral temporal	20	83,3	Emotional
↑ High-beta (Prefrontal cortex)	Prefrontal	7	29,2	Anxiety, hypervigilance
Encephalopathy/Epileptiform signs	Right frontal, diffuse	3	12,5	Cognitive disturbance, affective issues

Table 2 highlights the neurophysiological patterns observed in the 24 children who underwent q-EEG assessment. The most common abnormality was bilateral temporal lobe power loss (83,3%), indicating emotional dysregulation and sleep problems. High beta waves in the prefrontal cortex were present in 29,2% of cases, which are generally associated with anxiety and hypervigilance. A small proportion (12,5%) showed signs of encephalopathy or epileptiform activity, indicating more severe cognitive or affective dysfunction.

Integration Findings

The integration of behavioural and neurophysiological patterns yielded a unified pattern. The pattern showed that there was a relationship between bullying victimization and psychological distress and measurable changes in brain function. Increased stress scores correlated significantly with q-EEG findings, specifically decreased power in the bilateral temporal lobes and increased high beta activity in the prefrontal cortex. These brain regions are implicated in emotional regulation, threat perception, and cognitive processing, suggesting that chronic psychosocial stress disrupts neurodevelopmental pathways.

Notably, behavioural symptoms such as irritability, sleep disturbances, and difficulty concentrating were reflected in the neurophysiological profiles of the children studied. The argument for the use of q-EEG as an objective diagnostic tool in forensic and clinical evaluations may be strengthened by the mapping of these findings.

Discussion

Our hypothesis that the stress of childhood bullying can lead to measurable neurophysiological abnormalities is strongly supported by our results. Repetitive decreases in alpha and beta waves in the temporal lobe may impair emotional processing and potentially lead to sleep disturbances (Harrewijn, Molen, Westenberg, 2016; Wang et al., 2025). Children who have experienced trauma often exhibit temporal lobe abnormalities, given the lobe's function in processing memories and emotional experiences (Mclaughlin et al., 2020; Schiavone, Mckinnon, Lanius, 2018). Previous studies on the relationship between increased vigilance and anxiety and stress responses in pediatric populations have supported the association of high beta wave activity in the prefrontal cortex (Díaz, Tseng, Michalska, 2024).

Neurophysiological disturbances can alter the underlying function of the HPA axis and trigger emotional dysregulation (Lei et al., 2025; Mbiydzenyuy, Qulu, 2024). It is expected that q-EEG can profile the effects of stress objectively, which may strengthen its value in the medicolegal evaluation of child trauma (Marcu et al., 2025). These findings also support the inclusion of neurophysiological screening into child protection protocols.

From a legal standpoint in Indonesia, the findings of this study have significant relevance. According to Article 54 of Law No. 35 of 2014 concerning Child Protection, children in educational environments must be safeguarded from physical and psychological violence, including that perpetrated by peers. The q-EEG findings provide scientific evidence of psychological injury, especially when temporal and prefrontal abnormalities align with behavioural symptoms of trauma (Lewine et al., 2019; Sydnor et al., 2020).

Supreme Court Regulation or PERMA No. 3 of 2017 emphasizes the importance of multidisciplinary and humane handling of children in conflict with the law, both victims and perpetrators. In some cases, neurophysiological assessments such as q-EEG can play a dual role, namely early clinical detection and supporting evidence in a legal context (Rodríguez-Pellejero, Mulero-Henríquez, Santana Amador, 2024). In the case of cyberbullying, this data also intersects with Law No. 19 of 2016 concerning Information and Electronic Transactions (ITE), especially Article 27 (3) which criminalizes the distribution of content that causes emotional harm. In bullying cases, q-EEG data is particularly helpful in verifying the psychological impact, potentially supporting forensic claims. These interdisciplinary implications highlight the importance of integrating neuroscience into the forensic child protection system in Indonesia. We strongly recommend the formal incorporation of tools into clinical protocols and judicial evaluations, especially those involving cases of bullying and trauma experienced by children.

It is noteworthy that mapping q-EEG results with behavioral symptoms strengthens the argument for the use of neurophysiological data in legal and clinical evaluations. Unlike conventional psychological reports, which are often highly biased, q-EEG has been shown to be an objective and reproducible depiction of neurocognitive dysfunction. This finding is relevant in the context of child (victim) involvement in court proceedings, where trauma can influence the court and support more detailed interventions.

This research can serve as a foundation for arguments for a trauma-informed, multidimensional approach to child protection. Schools, clinicians, and legal practitioners must collaborate to detect early signs of trauma, especially in cases where behavioral symptoms alone may not fully capture the severity of internal distress. The integration of q-EEG data into standard screening processes may allow for more accurate triage, targeted support, and longitudinal monitoring of children at risk.

Our results, from a policy perspective, align with the objectives of Indonesian child protection law, which advocates the use of scientific tools in evidence collection. These results could strengthen mechanisms and ensure that children receive not only psychological support but also legal redress based on measurable injuries. Given that the brain changes observed here are indicative of neurological stress injuries, they could—if standardized—be considered forensic markers of trauma akin to physical wounds.

Conclusions

Bullying in childhood leaves measurable traces on brain function. This study demonstrates how integrating behavioral metrics and q-EEG patterns creates a powerful diagnostic and forensic

approach to identifying at-risk children. Given the findings of this study, we recommend the formal integration of q-EEG into forensic child assessments, especially in cases involving suspected psychological trauma. To interpret basic q-EEG findings, legal professionals, medical practitioners, and child advocates should be trained to collaborate in diagnosing and protecting at-risk children. Our hope is that future studies will use longitudinal designs to track neurophysiological changes over time and determine whether interventions can reverse or mitigate cortical dysfunction. A larger sample size across diverse demographics and cultural contexts will further enhance the study's generalizability. We recommend further exploration of combining q-EEG with other biomarkers—such as cortisol levels or neuroimaging—to support more robust forensic science. These steps will hopefully help establish standard protocols for complementing neurophysiological data in the child protection system, both clinically and legally.

Limitations. While this study provides valuable insights into the neurophysiological effects of bullying-induced stress, several limitations must be acknowledged. First, the cross-sectional design restricts the ability to draw causal inferences between bullying experiences and brainwave abnormalities. Longitudinal studies would be more suitable to assess the developmental trajectory of neurophysiological changes over time. Second, the relatively small q-EEG sample size (n = 24) limits the generalizability of the neurophysiological findings, despite the robust behavioural dataset (n = 2,781). Third, environmental factors such as family stress, nutritional status, and screen time—which could also influence brain function—were not controlled in this study. Lastly, the use of q-EEG, while valuable, is still an emerging tool in forensic contexts and may require further standardization before widespread adoption in legal systems.

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Appendix

Appendix A. Perceived Stress Scale (PSS-10)

The 10-item Perceived Stress Scale (PSS-10), adapted from BounceTogether and translated into Bahasa Indonesia, was used to assess subjective stress levels over the past month. Sample items include:

1. How often have you been upset because something unexpected happened?
2. How often have you felt that you were unable to control the important things in your life?
3. How often have you felt nervous and stressed?
4. How often have you felt confident about your ability to handle personal problems?
5. How often have you felt that things were going your way?

Responses were scored on a 5-point Likert scale ranging from 0 ("Never") to 4 ("Very often"). Positive items (Items 4, 5, 7, 8) were reverse-scored. Total scores ranged from 0 to 40 and were categorized as follows:

- 0—13: Low stress
- 14—26: Moderate stress
- 27—40: High stress

Appendix B. Bullying Behavior Questionnaire (Modified)

A culturally adapted 20-item questionnaire was used to assess bullying-related behaviors. Items were divided into three categories: perpetrator (13 items), victim (1 item), and knowledge-based (6 items). Participants answered by marking either "Pernah" (Yes) or "Tidak Pernah" (No). Sample items include:

- I have been kicked by a friend on purpose. *(Victim)*
- I have hit a friend for no reason. *(Perpetrator)*
- It is acceptable to mock a classmate's appearance. *(Perpetrator)*
- I have sent a threatening message via social media. *(Perpetrator)*
- Calling classmates by offensive nicknames is common. *(Knowledge)*

This instrument helped identify children who had been exposed to bullying, either as victims or perpetrators, and was used alongside clinical judgment to determine victimization status.

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The authors declare no conflict of interest.

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