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Profile in Healthy Congolese Children Aged 6 to 12 Years in Lubumbashi: Toward a Local Reference Standard

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Abstract

Introduction: Electroencephalography (EEG) is a crucial tool for assessing brain development in children. However, the lack of normative EEG data in Sub-Saharan Africa limits its clinical interpretation. This study aims to describe the baseline EEG profile in healthy Congolese children aged 6 to 12 years in Lubumbashi.

Methods: This descriptive cross-sectional study involved 416 healthy schoolchildren. Resting-state EEGs were recorded using international standards, including hyperventilation and photic stimulation. Parameters analyzed included alpha frequency, amplitude, symmetry, regularity, and eye-opening reactivity. Data were analyzed using Jamovi.

Results: The mean alpha frequency was 9.2 Hz, with a significant age-related increase ($p < 0.001$). EEG tracings were symmetric in 97.6% of children, regular in 91.3%, and reactive to eye-opening in 96.2%. No epileptiform activity was recorded. Non-pathological associated rhythms (mu, theta) were observed in 40–50% of cases.

Conclusion: The EEG characteristics observed in these healthy children are broadly comparable to international norms, with some context-specific variations. These findings establish a local EEG reference useful for clinical practice and neurodevelopmental research in the Democratic Republic of Congo.

Keywords: Electroencephalography; Child; EEG norms; Brain development; Central Africa

1. Introduction

Electroencephalography (EEG) is currently one of the most valuable and accessible tools for exploring brain activity, particularly in the field of child neurological development. Introduced in 1929 by Hans Berger, this technique records variations in the electrical potentials generated by cortical neurons at the scalp surface using electrodes positioned according to standardized anatomical landmarks (Berger, 1933; Niedermeyer & da Silva, 2004). Unlike morphological brain imaging (MRI or CT scan), EEG provides a real-time dynamic reading of functional cortical activity and is

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particularly sensitive to certain abnormalities that are not visible with conventional radiological methods (Thomas et al., 2003).

In children, EEG is of paramount importance, as it allows for the evaluation of different stages of neurodevelopment, the early detection of neurological or neurodevelopmental disorders, and guidance for differential diagnosis in the presence of non-specific clinical presentations such as attention disorders, learning difficulties, or behavioral abnormalities (Levitt, 2015; Thapar et al., 2016). The evolution of EEG tracings directly reflects the maturation of the central nervous system: progressive acceleration of the background rhythm (transition from theta to alpha activity), improved spatial organization of waves, and increased reactivity to stimulation (Plouin et al., 2013). These changes are influenced by various biological (genetic, nutritional), environmental (family environment, toxin exposure), and social (cognitive stimulation, access to education) determinants.

Several studies have highlighted the impact of the local context on brain development. For instance, it has been shown that factors such as chronic malnutrition, recurrent infections, perinatal deficiencies, and exposure to trace metals—frequent in mining regions—can lead to subtle but significant electroencephalographic abnormalities (Koba, 2018; Mudegereza, 2017). Moreover, the child's psychosocial environment, including parental education level, emotional stability, and housing conditions, plays a major role in shaping neural circuits (Suchdev et al., 2017; Okitundu et al., 2014).

Despite the growing recognition of these interactions, in Sub-Saharan Africa—and particularly in the Democratic Republic of Congo (DRC)—EEG reference norms adapted to the local context remain nonexistent. Most clinical laboratories still rely on reference curves established from European or North American populations, without adjustments for African physiological, nutritional, and environmental realities (Séraphin, 2013). This scientific gap seriously compromises clinicians' ability to accurately interpret EEG tracings of Congolese children and to detect potential developmental abnormalities at an early stage.

In Lubumbashi, the second largest city in the DRC, children are exposed to multiple factors likely to influence their brain development: persistent malnutrition in some peripheral neighborhoods, environmental pollution linked to mining activity, unequal access to healthcare, and varied levels of school stimulation. Local observations have already reported EEG slowing in children exposed to these conditions, notably related to malnutrition or exposure to heavy metals such as lead or cobalt (Koba, 2018; Bugeme, 2015). However, these studies have been limited in sample size and have not yielded a reliable, reproducible reference profile for Congolese children.

In light of this situation, there is an urgent need to develop normative EEG data tailored to the Congolese context, particularly among children aged 6 to 12 years—a critical period for consolidating cognitive, attentional, and academic functions. Establishing such norms is not only indispensable for rigorous interpretation of EEG tracings in clinical settings, but also essential for strengthening local capacity for early detection of neurodevelopmental disorders.

This study was therefore designed to describe the baseline electroencephalographic profile of healthy Congolese children aged 6 to 12 years in Lubumbashi, taking into account major neurophysiological variables such as background rhythm frequency, amplitude, symmetry, regularity, and eye-opening reactivity. The ultimate goal is to propose a preliminary EEG reference norm adapted to the local context, which may guide future clinical practice in pediatric neurology and neuropsychiatry in the Democratic Republic of Congo.

2. Methods

2.1. Study type, setting, and period

This research was conducted as an observational, cross-sectional, descriptive, and analytical study carried out between October 1, 2022, and July 27, 2023, in the city of Lubumbashi, the capital of Haut-Katanga Province, Democratic Republic of Congo (DRC). Lubumbashi is a densely populated and rapidly growing urban center marked by multiple socioeconomic and environmental disparities, making it a relevant setting for studying neurodevelopmental profiles. Electroencephalographic recordings were performed in health centers, schools, and community sites distributed across the eleven urban and peri-urban health zones of Lubumbashi, thereby capturing a wide range of socio-environmental backgrounds.

2.2. Target population and inclusion criteria

The target population consisted of presumed healthy children aged 6 to 12 years—a pivotal period in neurocognitive development corresponding to the consolidation of executive functions, attention, language, and social cognition. Inclusion in the study sample was based on the following criteria:

- Belonging to the specified age group (6–12 years) at the time of EEG recording;
- Residence in the city of Lubumbashi for at least two years, to minimize migratory or transient exogenous influences;
- Absence of documented neurological or psychiatric history, including epilepsy, developmental disorders, meningitis, encephalitis, or severe head trauma;
- Normal neuro-somatic examination performed on the day of recording;
- Provision of free and informed consent from parents or legal guardians.
- Non-inclusion and exclusion criteria
- Children with the following characteristics were excluded to ensure the validity of the data:
- Medical or neurological history likely to affect EEG (active epilepsy, cerebral malaria, anticonvulsant treatment, previous neuroinfections);
- Suspected developmental delays in motor or language skills based on school or family history;
- Presence of sensory disorders (blindness, deafness), severe motor disabilities, or any unstable chronic condition;
- Agitation or inability to cooperate during EEG recording despite a prior adaptation phase.

2.3. Sampling strategy and sample size

The sample was selected using stratified sampling proportional to the population of each health zone.

The minimum required sample size was calculated at 378 children. Considering an anticipated 10% rate of non-response or exclusion, the final sample size was set at 416 children, averaging approximately 38 children per health zone, thereby ensuring balanced spatial representativeness.

Electroencephalographic (EEG) recording

EEG recordings were conducted under standardized conditions using a portable CONTEC KT88-3200 device with 16 channels, configured according to the international 10–20 system adapted for children. Recordings were performed during the day in a calm environment at ambient temperature, with moderate lighting, following an adaptation phase of 10–15 minutes.

Each EEG session lasted about 30 minutes and included:

- A resting phase with eyes closed (baseline rhythm);
- Eye opening and closing to evaluate cortical reactivity;
- A 3-minute hyperventilation test (deep and rapid breathing at 20 cycles/minute);
- Intermittent photic stimulation (IPS) at frequencies ranging from 1 to 20 Hz.
- EEGs were interpreted by two independent neurophysiologists, with arbitration in case of disagreement. The following parameters were analyzed:
- Dominant background rhythm frequency (Hz);
- Mean amplitude (μV);
- Interhemispheric symmetry;
- Regularity of the tracing;
- Reactivity to eye opening;
- Presence of associated physiological rhythms (mu, theta, beta);
- Response to IPS and hyperventilation;
- Presence of atypical graphoelements without pathological value.

2.4. Statistical analysis

Data analysis was performed using JAMOVI software (version 2.3.21), a user-friendly platform built on R, enabling robust and reproducible statistical analyses.

Ethical considerations

The study was approved by the Ethics Committee of the University of Lubumbashi and adhered to the principles of the Declaration of Helsinki on research involving human subjects. Written informed consent was obtained from each parent or legal guardian. Data were handled anonymously and confidentially.

3. Results

3.1. General characteristics of the study population

Table 1 Sociodemographic and clinical characteristics of the children (n = 416)

Variables	**Modalities / Mean ± SD**	**n**	**Percentage (%)**
Mean age	9.1 ± 1.9 years	—	—
Sex	Boys	213	51.2
	Girls	203	48.8
Handedness	Right-handed	396	95.2
	Left-handed	20	4.8
Mode of delivery	Vaginal	294	70.7
	Cesarean	122	29.3
Normal nutritional status	—	322	77.4
School level	Lower primary (grades 1–3)	218	52.4
	Upper primary (grades 4–6)	198	47.6

The sample was balanced by sex, with a slight male predominance. The mean age (9.1 years) corresponds to the period of stable establishment of the alpha rhythm. The very high proportion of right-handed children (95.2%) reflects the classical pattern of cerebral dominance. The high rate of vaginal delivery and good nutritional status (77.4%) reinforce the validity of the "neurologically healthy" profile selected.

3.2. EEG background rhythm (alpha frequency)

Table 2 Age groups and mean alpha frequency

Age group (years)	**Mean alpha frequency (Hz)**
6 – 8	8.7
9 – 10	9.3
11 – 12	9.6

A significant increase in background rhythm frequency with age was observed ($p < 0.001$, ANOVA test). This trend follows the natural course of brain development, marked by increasing cortical connectivity. These values are slightly lower than those reported in European studies (10 Hz), suggesting local environmental specificities (nutrition, stimulation, overall health).

3.3. Basic EEG parameters

Table 3 Basic EEG parameters in healthy children

Parameter	Mean value ± SD / %
Alpha frequency (all ages)	9.2 ± 0.8 Hz
Occipital EEG amplitude	63.4 ± 12.2 µV
Symmetric EEG tracing	97.6%
Regular EEG tracing	91.3%
Eye-opening reactivity	96.2%

These parameters reflect normal EEG activity in most children. The mean frequency of 9.2 Hz falls within the expected range for this age group. Symmetry and regularity of tracings indicate good cortical organization, while strong reactivity to eye opening is a marker of functional maturity of the occipital cortex.

3.4. Response to stimulation (hyperventilation and IPS)

Table 4 Response to stimulation

Type of stimulation	Normal response observed	Percentage (%)
Hyperventilation (theta/delta activation)	Yes	71%
IPS (photic synchronization)	Yes	92%
Epileptiform activity during IPS	None	0%

The normal response to hyperventilation (transient non-pathological slowing) in 71% of cases is physiological. A good response to IPS in 92% of cases indicates proper cortical responsiveness to rhythmic visual stimulation. The complete absence of paroxysmal or epileptiform activity reinforces the neurological health of the study group.

3.5. Non-pathological associated EEG activities

Table 5 Associated EEG activities observed in children

Associated activity	Presence (n)	Percentage (%)
Mu rhythm (central)	51	12.3
Transient frontal theta waves	161	38.7
Spindles (during calm wakefulness)	40	9.6
Suspected epileptiform activity	0	0

Mu rhythms, theta waves, and spindles are benign elements frequently observed in healthy children. Their presence does not indicate pathology. These findings are consistent with descriptions by Plouin and Kaminska (2013) in normal pediatric EEGs. The absence of epileptiform activity further confirms the lack of major structural abnormalities in this sample.

3.6. EEG–age and clinical correlations

Table 6 EEG–age and clinical correlations

Correlation analysed	Coefficient (r)	p-value
Age ↔ Alpha frequency	0.42	< 0.001
Head circumference ↔ EEG amplitude	0.19	0.030

The increase in alpha frequency with age is a clear indicator of neurophysiological maturation. The moderate correlation between head circumference and EEG amplitude suggests a link between brain physical growth and its electrical resonance, though other environmental factors may also play a role.

3.7. Comparison by sex

Table 7 Comparison by sex

Parameter compared	Girls (mean)	Boys (mean)	p-value
Alpha frequency	9.3 Hz	9.1 Hz	0.21
EEG amplitude	64.2 µV	62.6 µV	0.18
Eye-opening reactivity	96.8%	95.6%	0.55

No significant differences were found by sex. This aligns with the findings of Lenroot & Giedd (2010), who reported that neuroelectrical differences between genders appear only after puberty. This justifies the pooled non-gendered analysis in this age group.

4. Discussion

This study aimed to establish a baseline electroencephalographic profile in healthy Congolese children aged 6 to 12 years living in Lubumbashi, in order to identify the normal EEG features in an African context that remains poorly documented. The findings obtained are generally consistent with those reported in the international literature, while also revealing certain specificities linked to the local environment. Cross-analysis with data from more than thirty reference authors enriches the scientific interpretation and underscores the value of a contextualized approach in defining pediatric EEG norms.

4.1. General characteristics and representativeness of the sample

The study population showed a balanced sex distribution and a mean age of 9.1 ± 1.9 years, corresponding to the critical period for consolidation of the posterior alpha rhythm. These findings are in line with those of Petersen and Eeg-Olofsson (1971) and Scraggs (2012), who emphasized the importance of this developmental stage in EEG maturation. The predominance of right-handedness (95.2%) is consistent with classical findings by Hagne et al. (1973), reflecting typical cortical organization. Moreover, the good nutritional status observed in more than three-quarters of the children (77.4%) is crucial, as numerous studies—including those of Guerrant et al. (2008) and Suchdev et al. (2017)—have demonstrated the determinant role of nutrition in neurocognitive and electrical brain development.

4.2. Dominant background rhythm frequency

The mean alpha frequency of 9.2 Hz, with a significant age-related increase ($p < 0.001$), reflects expected cortical maturation. This phenomenon, well documented by Niedermeyer & Lopes da Silva (2004), Grandy et al. (2013), and Marshall et al. (2002), corresponds to the strengthening of thalamo-cortical connections and increasing organization of neural networks. The fact that this frequency remains slightly lower than those reported in European or North American studies (where the mean reaches 10–10.5 Hz in preadolescents, according to Klimesch et al., 1993, and Stroganova et al., 1999), may be explained by differences in living conditions, early cognitive stimulation, or the socio-educational environment. This hypothesis is supported by Haegens et al. (2014), who demonstrated that alpha activity is sensitive to contextual determinants.

4.3. Amplitude, symmetry, and reactivity of EEG tracings

The mean amplitude recorded (63.4 ± 12.2 µV) is consistent with normal values described in pediatric literature (Pampiglione, 1972; Corbin & Bickford, 1955). This amplitude reflects good neuronal synchronization and satisfactory cortical conductivity. The fact that most children presented with symmetric (97.6%) and regular (91.3%) EEG tracings reinforces the hypothesis of well-structured brain activity at this age. Studies by Kellaway (1979) and Kaminska et al. (2019) confirm that these parameters are robust indicators of normality in children. Eye-opening reactivity (96.2%) is also an essential criterion, reflecting the physiological ability of the occipital cortex to inhibit alpha activity. This response, described by Barry et al. (2009) and Lindsley (1939), is a fundamental marker of the functional integrity of the visual network.

4.4. Responses to stimulation: hyperventilation and IPS

The EEG response to hyperventilation observed in 71% of children, in the form of transient slowing, is typical of normal tracings according to the criteria of Mizrahi & Kellaway (1987) and André et al. (2010). This response is more pronounced in younger non-epileptic populations, as indicated by Marcuse et al. (2008), and reflects physiological cortical sensitivity to respiratory alkalosis. The response to intermittent photic stimulation (IPS), present in 92% of children, confirms visual maturation and rhythmic signal integration. Its absence in 8% of cases may be due to immaturity or individual variability, a phenomenon described by Dreyfus-Brisac (1975) and in NCBI Bookshelf protocols (2022). The complete absence of epileptiform activity further validates the inclusion of neurologically healthy subjects.

4.5. Non-pathological associated EEG activities

The observation of rhythms such as transient theta (38.7%) or the mu rhythm (12.3%) is common in this age group. According to Ebersole & Pedley (2003), these elements are normal and may appear during wakefulness or rest without pathological significance. Their recognition is crucial to avoid diagnostic errors. Plouin and Kaminska (2013) have stressed the importance of EEG interpreter training in pediatric contexts, particularly in regions lacking local norms.

4.6. Correlations between EEG and clinical variables

The positive correlation between age and alpha frequency ($r = 0.42$) is an indicator of cortical development, widely reported in studies by Clarke et al. (2001) and Stroganova et al. (1999). This evolution is linear but modulated by life context, as highlighted by Kinney-Lang et al. (2017). The weak correlation between head circumference and EEG amplitude ($r = 0.19$, $p = 0.03$) suggests a partial anatomo-functional relationship, as also noted by Bos-Bayard et al. (2022), though interpretation remains limited in the absence of complementary neuroimaging.

4.7. Sex-based comparison

The absence of significant differences between girls and boys in alpha frequency, amplitude, or symmetry confirms that sex is not a discriminating factor before puberty, as demonstrated by Lenroot & Giedd (2010) and Marcuse et al. (2008). Inter-sex differences generally emerge during adolescence under hormonal influence but remain moderate in terms of resting EEG structure, according to meta-analyses by Miskovic et al. (2015).

Overall, the results of this study confirm that healthy Congolese children aged 6 to 12 years present physiological EEG tracings broadly comparable to those of children from other regions of the world. However, slight variations observed in alpha frequency or IPS response highlight the importance of developing local EEG reference standards that account for contextual specificities nutrition, environment, cognitive stimulation, and genetic factors. These findings support ongoing calls for the decolonization of biomedical norms and the adoption of standards adapted to the realities of countries in the Global South (Janiukstyte et al., 2023; Kinney-Lang et al., 2017).

5. Conclusion

This study represents a significant first contribution to establishing a reference electroencephalographic profile for healthy Congolese children aged 6 to 12 years in Lubumbashi. The collected data show an EEG organization largely consistent with international norms, characterized by regular, symmetric, and reactive tracings, as well as a linearly increasing alpha frequency with age. These findings reflect functional brain maturation typical of this developmental stage.

However, certain specificities such as a slightly lower alpha frequency compared to that observed in Europe or North America, and variations in responses to stimulation suggest the influence of environmental, nutritional, and sociocultural factors on local neurophysiological dynamics. The absence of epileptiform activity in the entire sample validates the rigorous selection of neurologically healthy children and strengthens the relevance of the established profiles.

The detailed analysis highlights the importance of developing local EEG reference standards in Central Africa, adapted to geographical and cultural contexts, in order to improve diagnostic accuracy in child neuropsychiatry. These results may serve as a basis for the development of standardized interpretation grids, clinician training, and research on neurological and neurodevelopmental disorders in the region.

Recommendations

- **For clinical practice**
  - Develop local EEG norms according to age and the Congolese environmental context, to complement international standards.
  - Systematically integrate EEG analysis into neurological and neuropsychiatric evaluation of children, particularly in cases of suspected cognitive, language, or attention disorders.
  - Train local technicians and neurologists in the interpretation of pediatric EEGs, with an emphasis on recognizing non-pathological associated activities (such as the mu rhythm and frontal theta waves).
  - Create an EEG reference network bringing together hospitals, universities, and specialized health centers to harmonize practices across the DRC.
- **For policymakers and public health authorities**
  - Support the acquisition of modern, mobile, and affordable EEG equipment for regional hospitals.
  - Fund early neurodevelopmental screening campaigns in schools and communities.
  - Promote a strengthened child nutrition policy, directly linked to optimal brain development.
- **For research**
  - Extend the study to other age groups (0–5 years, 13–18 years) and to other cities or rural areas to refine national EEG norms.
  - Cross EEG data with neurocognitive, educational, and behavioral tests (e.g., NEPSY-II, WISC-V).
  - Investigate the influence of environmental exposures (mining-related pollution, heavy metals, deficiencies) on EEG activity in children.
  - Develop predictive models of EEG abnormalities in conditions such as epilepsy, ADHD, or autism spectrum disorders, using locally generated databases.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from the parents or legal guardians of all children include in the study.

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