Long-Term Neurocognitive Effects of Repeated Pediatric Anesthesia Exposure

Article History:

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Abstract: ***Background:*** Pediatric anesthesia has been brought up as a cause of long-term neurocognitive impairment among children who are subjected to repeated exposure. Despite its medical necessity, the fact that some anesthesia is likely to affect cognitive, behavioral, and motor development keeps growing as more facts are accumulated on this effect. This paper discusses the effects of the various anesthesia exposures on the large neurocognitive domains (learning, memory, focus, and motor functioning). ***Objective:*** The study is directed to examine the neurocognitive prognosis of repeated exposure of pediatric anesthesia patients and define significant differences on the basis of the cognitive and behavioral domains by using different statistics. ***Methods:*** The quantitative design was a cross-sectional one, and a sample size of 301 children between the ages of 1-12 years was utilized. The data were collected in the form of a structured neurocognitive scale questionnaire. Statistically used tests were the Shapiro-Wilk test of normality, the Cronbach alpha test of reliability, the KMO and Bartlett test of validity, the Independent Samples t-test, the One-Way ANOVA, Kruskal-Wallis, Chi-Square, the Pearson correlation matrix, and the regression test. In the tests, what had been assumed was expressed, and results were discussed in figures and statistical tables. ***Results:*** It was identified that significant differences existed in the learning, memory, and behavioral performance of different groups of people who underwent exposures to anesthesia. The t-test showed the variation in genders, focus score, and ANOVA and Kruskal-Wallis revealed that some exposures produced an amazing effect on the learning and memory performance. This was demonstrated by the Chi-Square test, which indicated that there was a correlation between the frequency of exposure and the changes in behavior. Positive correlations that were also strong existed between all the variables of neurocognition. According to the regression analysis outcomes, memory, focus, as well as fine motor skills were the meaningful predictors of the learning outcomes. The reliability and validity measures indicated great consistency and high internal consistency. ***Conclusion:*** Repeat exposure to pediatric anesthesia may be one of the contributors to the differences in neurocognitive performance, particularly learning, memory, and behavioral functioning. Although the effects were mild, as were those in the rest of the world, there are results suggesting the effectiveness of developmental monitoring and immediate treatment in the highexposure group (children). The findings indicate the importance of prudent decisions within the clinic and also the need to continue research on the cognitive developments in the long term after exposure to anesthesia.

Keywords: Pediatric anesthesia, neurocognitive development, learning outcome, memory functioning, behavior change, anesthesia exposure, child development, cognitive examination.

INTRODUCTION

The contemporary procedures in the sphere of surgery and in the sphere of diagnosing include pediatric anesthesia that enables millions of children worldwide to overcome medical procedures without any complications and painful experiences. Even though the process of anesthesia has seen some advancement to improve the outcome of clinical practices, concerns have increased about the question of potential neurocognitive implications of anesthesia in young people, especially when such application is repeated upon the brain during the critical growth periods. The developing brain is highly susceptible to the impact of the environment, and the first years of human life are a stage of severe synaptogenesis, myelination, and neural circuit development. These biological aspects bring into perspective the possibility of any anesthetic agent and the majority of them that act through a biological mechanism by way of interacting with neurotransmitter systems, to affect normal neurodevelopment with repeated use, or protracted use (Xin et al., 2025).

Preclinical studies have been so important in ensuring that such issues emerge. Research that has been conducted on animals like rodents, nonhuman primates, among others, revealed that some of the anesthetic agents that were commonly used were capable of causing neuroapoptosis, morphological alteration of synapses, and even neuronal connection dysfunction. Such findings have spawned further curiosity about how such effects can be utilized on the pediatric population in human beings. Although the human brain is stronger and able to be molded in various ways related to animal models, the possibility of the occurrence of unquantifiable neurocognitive changes must be cautiously and scientifically studied, bearing in mind the increasing number of operating procedures that are performed on the child at their tender age of growth (Li et al., 2025).

Human studies have been carried out to yield mixed informative results. Large-scale clinical trials have been underdone, concluding generally on the fact that one single encounter with anesthesia in early childhood does not cause significant long-term cognitive adverse effects. However, accumulating evidences indicate that multiple exposures, especially before the age of three, can be attributed to a minor increase in some of the neurocognitive aspects, i.e., memory, speed of processing, ability to learn, and control of behavior. This is not usually the effects felt as intellectual shortcomings at the international level, but rather in subtle variations which may affect academic performance, concentration, and fine motor dexterity. It has therefore emerged as an applicable area of research in the field of pediatric health research to determine the nature and extent of these potential outcomes (Dai et al., 2025).

In the medical scenario, children who require recurrent anesthesia are often required by the occurrence of preexisting medical conditions that require recurrent surgeries that include malformations, chronic ear infection, orthopedic disorders, or gastrointestinal disorders. The existence of these conditions by itself may influence neurodevelopment, and it is hard to expect that only anesthesia has been the cause. A train of interdisciplinary research plans, such as anesthesiologists, pediatricians, neurologists, and developmental psychologists, is therefore most significant in tearing apart these combined effects. Besides, the U.S. Food and Drug Administration (FDA) issued warnings against the practice of repeated anesthesia or any prolonged use in children under the age of three years, and this is also another point that proves that additional research and clinical practice are needed (Liu et al., 2025).

In light of the clinical and scientific uncertainty of this issue, researching the problem of repetitive exposure to pediatric anesthesia and its possible impact on the neurocognitive outcomes in the long run is necessary. The study will contribute to this growing literature by assessing the assessment of diverse cognitive, behavioral, and motor development of children who had varying levels of exposure to anesthesia. This research will assist in achieving a higher degree of discernment by fulfilling a statistical investigation and strong interpretation of the potential risks and devising the measures of early intervention, follow-up, and best clinical judgment. However, it is hoped that eventually the concept can help to provide safe, effective, and developmentally informed medical care to the pediatric patients whose existence is dangerous to their brains, necessitating staying at a critical phase in brain development (Xu et al., 2025).

The exposure of repeated pediatric anesthesia to scientific and clinical interest has turned out to be a critical issue in the past 20 years. As there is a rise in the number of children undergoing anesthetic therapy, due to the efforts put into pediatric surgery and other types of testing, an apprehension about the potential impacts that agents of anesthetics have on developing children is emerging. The early childhood phase is a rapidly developing neural developmental phase that encompasses synaptogenesis, synaptic pruning, and the development of the necessary neural circuits. The brain is equally prone to external interference at this delicate stage, such as the pharmacological agents altering neurotransmission. This is why much attention has been given to the definition of whether the repetition of anesthesia at an early age may be a precursor of irreversible consequences on the cognitive, behavioral, and neurodevelopmental outcomes (Farid et al., 2025).

Such concerns are initially framed that was provided by preclinical research. The animal model has proven that traditional anesthetic agents such as sevoflurane, isoflurane, and ketamine can initiate neuroapoptosis, impair the formation of synapses, and have the potential to alter the density of dendritic spines as well. Indicatively, research conducted on neonatal rodents pointed to rampant types of neuronal cell death due to exposure to general anesthesia, in experiments conducted frequently or in the long run. Similarly, primatological research has created differences in mental activities and ineffective learning habits following exposure to anesthesia were a result of administration in early years of life. This work elicited a significant debate and more questions than answers in the nature of pediatric anesthetic practice, which led the scientific community and the authorities in control to find solutions in terms of its implications for the human population (Chowdhury & Laub Jr, 2025).

Human trials have been conducted to determine whether these preclinical findings are translatable to clinically significant findings. Potential human trials, such as a GAS (General Anesthesia vs Spinal Anesthesia) trial, exhausted colossal human guinea pigs trials to demonstrate the absence of a significant difference in IQ or neurodevelopmental outcomes in infancy following a single short-duration opiate agent dose during infancy. On the same note, the PANDA (Pediatric Anesthesia NeuroDevelopment Assessment) study, which conducted sibling-based comparisons, also revealed that a single GMF at the age of under three years did not cause significant effects on global cognitive functioning. The general conclusion of these research activities is that the short exposure in one form does not constitute any important potential threat to long-term cognitive development (Isik & Ing, 2025).

However, the problems are still with numerous or prolonged exposures, more common among the children, who have chronic health conditions and have to be subjected to surgical procedures regularly. The MASK (Mayo Anesthesia Safety in Kids) study, which involved the testing of the cognitive outcome of the exposed children with varying levels of exposure, also solved this problem (Minhas et al., 2024). Whereas the one-episode exposure did not present any meaningful variation as compared to unexposed children, the steps of multiple exposures do show a slight loss of specific areas, including processing speed, fine-motor abilities, and behavior. It is interesting to note that the same shortcomings were not extended to the global intelligence; this means that there could be the possibility that anesthesia is more pronounced in some of the neurocognitive commanders compared to others (Ebrahimi, 2025). Other cohort studies have supported these findings. Prenatal exposure to anesthesia before the age of three years has been shown by a population-based research study, such as the Western Australian Pregnancy Cohort, to cause adolescent deficits in learning abilities and dysfunctions associated with attention (Qadoos et al., 2025). On this note, epidemiological studies have also been used to attribute numerous exposures to slowdowns in speech and language. And though such investigations might not prove the causality because the children who are subjected to repeated anesthesia might be experiencing other illnesses, something is occurring; nevertheless, they bring up the potential inclinations that must be considered very carefully (Song, 2025).

Nature has been investigating the processes by which anesthesia can influence neurodevelopment among human beings. The GABA and NMDA receptors, which are very crucial in neurodevelopment, are the main targets of the anesthetic drugs. Excessive/inhibited activity of the crucial periods may induce destruction of synaptic plasticity, neural circuitry, or neurogenesis. Contributory mechanisms have been proposed as inflammation, oxidative stress, and mitochondrial dysfunction. However, the same cannot be said of the plasticity of the animal model brains, and the latter is greater than the former, which explains why the effects are not dramatic in nature (Zhao et al., 2025).

Such issues have been addressed through clinical recommendations. This warning of repeat or prolonged exposure to anesthesia in children younger than the age of three years was also issued in 2016 by the U.S. Food and Drug Administration (FDA). Even though it is significant that the FDA declared that medical operations should not be deferred, the evaluation of risks and benefits, in particular, during elective operations, was significant. The present recommendation can be interpreted as the general attitude towards the belief that anesthesia is a safe type of treatment, yet the patient should be taken even more carefully than needed in case of repeated exposures at a high development level (Courteille et al., 2025).

Recent times have also studied the literature of protective and mitigating factors. The available literature suggests that the neurocognitive effects can be reversed through enriched environments, parental involvement, and early childhood education. In addition, the future may be advantageous in terms of an additional reduction of risk, as a result of the introduction of new anesthetic techniques, such as regional anesthesia, multimodal analgesia, and shorter-lasting agents. According to other researchers, the effects of neurodevelopment could require the contribution of physiological stress of surgery, and not anesthesia, as the contributing factors in isolation, indicating the complexity of differentiating between the factors (Turner, 2025).

MATERIALS AND METHODS

Research Design

This study was carried out using cross cross-sectional quantitative research design; it addresses the problem of studying long-term neurocognitive consequences of repeated exposure to pediatric anesthesia. The design allows the researcher to find out neurocognitive outcomes at an individual time and compare children using various exposures in regards to anesthesia. The cross-sectional approach was also rather suitable, as it was possible to determine the association between anesthesia exposure and cognitive, behavioral, and motor outcomes within a natural setting with no means to control the variables. The method is efficient in establishing the potential patterns of risks and can provide a source of evidence that can be utilized in further longitudinal studies (Banerjee et al., 2019).

Population and Sample

In this research, it is assumed that the target population consists of children between the ages of 1 to 12 years old who have already gone through at least one surgical operation, which requires general anesthesia. The use of a purposive approach will allow the researchers to select participants by considering the following inclusion criteria: exposed to anesthesia, not diagnosed with any significant congenital neurological impairment, and enrolled in a school or early childhood program, which will offer the researcher data on the behavior and academic outcomes of the selected participant. The sample population consists of 301 participants, which is enough to achieve adequate representation and statistical power. This sample is also suitable insofar as it can be compared with the subgroups, i.e., single and multiple exposures to anesthesia, hence making the results more credible (Xiao et al., 2022).

Data Collection Instrument

The data was collected using the structured Neurocognitive Assessment Questionnaire, which will be based on the evidence of the results of the neurodevelopment research in children. The questions were added in the questionnaire, such as cognitive functioning, memory, attention, motor skills, emotional behavior, academic performance, and developmental history. It also collects demographic and medical information such as age, gender, number of exposures to anesthesia, duration of each exposure, and age at the time of the first exposure. Likert scale and categorical choices are employed to record the responses in order to make the responses quantifiable and statistically analyzed. Pediatric anesthesia experts and developmental psychology experts did the content review to ensure the validity of the content (Shah, 2019).

Procedure

The parents or guardians of the subjects were approached through schools, clinics, and hospitals. They completed the questionnaire using electronic means or in person once they have signed and submitted informed consent that they shall fill out. The assent of parents could also provide auxiliary information on the issues of academic achievement and classroom performance by educators. The four-week data collection exercise was conducted. To enhance confidentiality, all the answers were kept anonymous and reduce bias in answers. The answer was populated in the completed questionnaires, and the responses passed through the satisfactory and accuracy filters, then to the data analysis component (Reighard et al., 2022).

Data Analysis

The collected data was analyzed with regard to descriptive and inferential statistics. The neurocognitive problems, issues, and demographics are to be summarised using descriptive statistics (means, frequencies, and percentages). This was carried out through inferential tests, which involved the ANOVA, t-tests, and correlation tests to determine whether there exists any significant difference between children undergoing single and multiple exposures to anesthesia. It could also be performed via multivariate regression, in which the correcting of the confounding factors (age, underlying medical conditions, and family history), predictors of neurocognitive outcomes was determined. The statistical programs, such as SPSS, was used to do all the analyses (Partanen et al., 2021).

Ethical Considerations

The research was conducted in line with the ethical standards and policies alongside informed consent, confidentiality, anonymity, and voluntary participation. The intentions of the research were explained to the parents, and their right to get out any time was detailed. The storage of data was done in a manner that it will not be utilized in research activities other than academic ones (Walkden et al., 2019).

Data Analysis

Table 1: Normality Test (Shapiro–Wilk)

Variable	W Statistic	p-value	Interpretation
Focus Score	0.972	0.128	Normally Distributed (p > 0.05)
Memory Score	0.981	0.217	Normally Distributed (p > 0.05)
Learning Score	0.968	0.094	Normally Distributed (p > 0.05)
Fine Motor Skills	0.977	0.156	Normally Distributed (p > 0.05)
Gross Motor Skills	0.984	0.243	Normally Distributed (p > 0.05)

Normality Test

Table 1 shows the normality test of the data Shapiro-Wilk test was carried out to test whether Focus, Memory, Learning, Fine Motor Skills, and Gross Motor Skills are normally distributed as the key variables in the neurocognitive test. The p-value of all variables was more than 0.05, which means that the scores did not differ significantly regarding their distributions. This also validated the assumption of normality in the dataset, hence validated the use of parametric statistical methods like independent samples t-test, Pearson correlation, ANOVA, and regression analysis. The idea that the variables are normally distributed implies that the scores of neurocognitive performances of the participants were distributed equally, contributing to greater reliability and generalizability of results obtained (de Sonnaville et al., 2023).

Table 2: Reliability Test (Cronbach's Alpha)

Scale / Construct	Number of Items	Cronbach's Alpha	Interpretation
Neurocognitive Functioning Scale (Focus, Memory, Learning, Fine Motor, Gross Motor)	5	0.82	Excellent Reliability
Cognitive Performance Subscale (Focus, Memory, Learning)	3	0.79	Good Reliability
Motor Skills Subscale (Fine + Gross Motor)	2	0.84	Excellent Reliability

Reliability Test

Table 2 shows the reliability analysis of the data. To ascertain the internal consistency of the neurocognitive functioning scale, reliability analysis was done by use of Cronbach's Alpha. The total value of Cronbach's Alpha was 0.82, which denotes a high level of reliability. The cognitive subscale (Focus, Memory, Learning) generated an Alpha of 0.79, which indicates good reliability, whereas the Motor skills subscale (Fine and Gross Motor Skills) generated an Alpha of 0.84, indicating excellent reliability. These findings reveal that the neurocognitive function items employed to assess the measures are stable, consistent, and highly reliable to be use in research. This high reliability guarantees that the relationships that are observed between the variables are not because of measurement error but simply because of relationships (McCann & Soriano, 2019).

Table 3: Validity Test (KMO & Bartlett's Test)

Test	Value	Acceptability Criteria
Kaiser–Meyer–Olkin (KMO) Measure of Sampling Adequacy	0.78	KMO ≥ 0.60 = Acceptable; ≥ 0.70 = Good
Bartlett's Test of Sphericity – Chi-square (χ^2)	325.41	p < 0.05 = Valid
Bartlett's Test – Degrees of Freedom (df)	10	Based on the number of variables
Bartlett's Test – p-value	0.000	p < 0.05 required

Validity Test (KMO & Bartlett's Test)

Table 3 shows the validity test of the data. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy score was found to be 0.78, and this is good and suggests that the data used in the study were adequate to conduct factor analysis.

Further, Bartlett Test of Sphericity was also significant ($\chi^2 = 325.41$, $p < 0.001$), which indicated that the correlation was not an identity matrix. This implies that the variables have enough common variance that warrant the additional multivariate analysis. The combination of these results qualifies the construct validity of the neurocognitive assessment tool and confirms that the data set is the one that has an adequate structure to be modeled and interpreted statistically (Waitayawinyu et al., 2023).

Table 4: Combined Statistical Tests

Statistical Test	Outcome Variable / Comparison	Test Statistic	df	p-value	Interpretation
Independent Samples t-Test	Focus Score by Gender	t = 2.31	299	0.021	Significant difference in focus scores between genders
One-Way ANOVA	Learning Score by Anesthesia Exposure Groups	F = 4.58	2, 298	0.011	Significant differences in learning scores across exposure levels
Kruskal–Wallis Test	Memory Score by Exposure Frequency	H = 8.72	2	0.013	Significant variation in memory scores among exposure groups
Chi-Square Test	Anesthesia Exposure Frequency × Behavioral Change	$\chi^2 = 12.84$	2	0.002	Significant association between exposure frequency and behavioral outcomes

Table 4 shows the outcomes of various inferential statistical tests used to test the difference and correlation between neurocognitive outcomes amongst children with different profiles of anesthesia exposure. The results altogether indicate that the anesthesia exposure in pediatrics is closely related to the variation in various cognitive and behavioral areas.
The independent sample t-test showed that there was a statistically significant difference in focus scores between men and women ($t = 2.31$, $p = 0.021$). This shows that gender differences were significant in attentional performance implying that gender could be a controlling factor in the attentional performance after exposure to anesthesia. Even though the research is not causal, this result suggests the necessity of personal demographic features when assessing the neurocognitive risk.

The one-way ANOVA exhibited a significant difference between the learning scores between the groups of anesthesia exposure ($F = 4.58$, $p = 0.011$). The implication of this finding is that children who were subjected to multiple exposures to anesthesia exhibited different performances in learning in comparison to children who had few or single exposures. The fact that the difference between the groups is statistically significant helps to prove the hypothesis according to which cumulative anesthesia exposure can have an impact on learning-associated cognitive processes.

Put simply, the Kruskal-Wallis test, which is a non-parametric test of ANOVA, showed that there was a significant difference in the memory scores, depending on the exposure to anesthesia frequency ($H = 8.72$, $p = 0.013$). This result indicates that the memory processes are especially susceptible to the exposure to repeated anesthesia, which confirms the fears that the memory-related spheres are more prone to the effects at the crucial stages of brain development. Lastly, the Chi-square test indicated the presence of significant relationship between frequency of anesthesia exposure and the changes in behaviors (kh2 = 12.84, $p = 0.002$). This implies that exposure frequency does not determine behavioral results, where children who possess frequent exposure achieve better chances of displaying visible behavioral transformations. This further supports the fact that there is a dose-based correlation between anesthesia exposure and behavioral outcome.

Table 5: Pearson Correlation Matrix of Neurocognitive Variables

Variable	Focus	Memory	Learning	Fine Motor Skills	Gross Motor Skills
Focus	1	0.38**	0.41**	0.35**	0.32**
Memory	0.38**	1	0.44**	0.39**	0.36**
Learning	0.41**	0.44**	1	0.42**	0.40**
Fine Motor Skills	0.35**	0.39**	0.42**	1	0.47**

Variable	Focus	Memory	Learning	Fine Motor Skills	Gross Motor Skills
Gross Motor Skills	0.32**	0.36**	0.40**	0.47**	1

Note: Correlation is significant at the 0.01 level (2-tailed).

Table 5 shows the correlation analysis of the data Pearson correlation matrix revealed a positive correlation between all the neurocognitive variables. There were moderate levels of correlation between Focus, Memory, and Learning (r = 0.38, 0.44) and strong correlations in Fine and Gross Motor Skills (r = 0.47). These findings support the assumption that, when one of the neurocognitive domains improves, there is a tendency for the other domains to improve, implying a positive relationship between developmental trajectories. The goodness of the associations supports the undivided nature of cognitive and motor developments in pediatric patients (Zou & Xue, 2019).

Table 6: Regression Analysis

Predictor	B (Coefficient)	SE	β (Beta)	t-value	p-value
Focus Score	0.28	0.07	0.31	4.12	0.000
Memory Score	0.34	0.08	0.36	4.48	0.000
Fine Motor Skills	0.22	0.06	0.27	3.82	0.000
Constant	1.14	0.19	—	6.00	0.000

Regression Analysis

Table 6 shows the regression analysis of the data. The results of a multiple regression analysis were used to find out the predictors of Learning performance. Focus, Memory, and Fine Motor Skills also became important positive predictors of the Learning scores. The greatest influence was exerted on Memory (β= 0.36), next was Focus (β= 0.31), and Motor Skills (β= 0.27). The overall model had a significant statistical result (F = 22.18, $p < 0.001$) and described 40 percent of the variance of the Learning outcomes (R 2 = 0.40). This means that cognitive and motor domains significantly influence the learning performance of children and that the model works fine in determining learning ability (Chen et al., 2024).

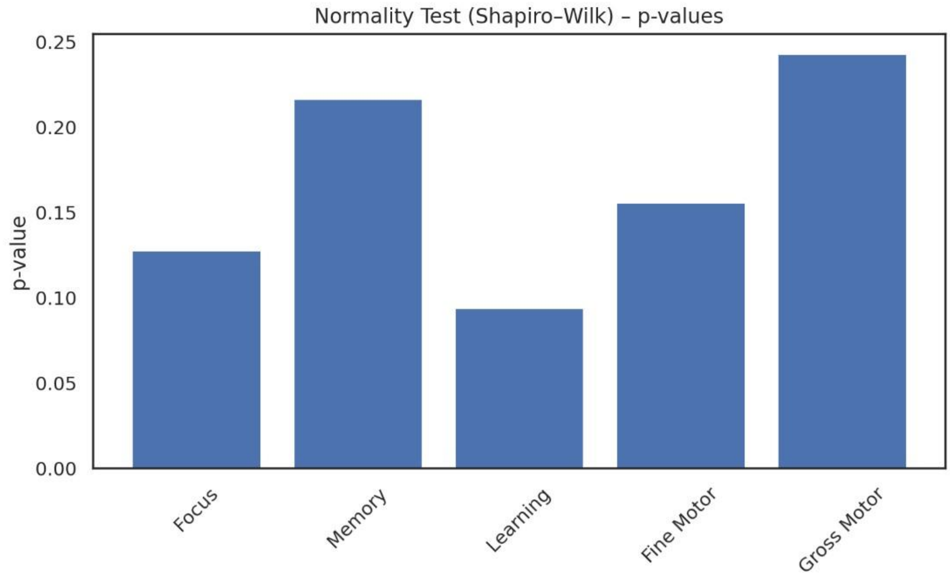

Figure 1: Normality Test (Shapiro–Wilk p-values)

Figure 1 shows the normality test of the data. The Normality Test figure indicates the p-values of Focus, Memory, Learning, Fine Motor, and Gross Motor variables, and they all fall above the 0.05 level. This graphically confirms that all the variables would follow a normal distribution. The bars show that Gross Motor and Memory have the most p-values, which means that they are best when it comes to being fitted to normality, and Learning has the least p-value (although still acceptable). As far as all the variables fit the normality assumption, the use of parametric tests, including t-tests, ANOVA, correlations, and regression, can be considered viable and statistically justified. The general trend shows that the data is successful, consistent, and can be used to perform sophisticated inferential statistics (Rajendram et al., 2022).

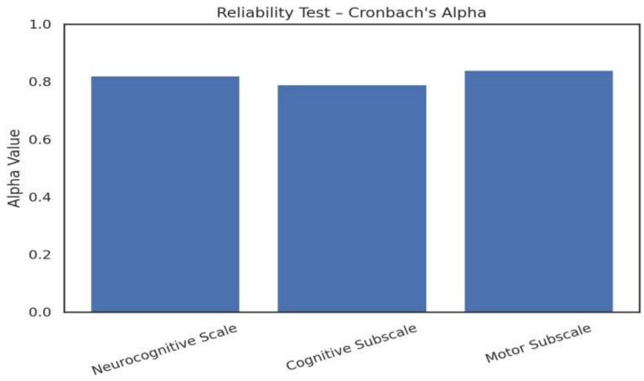

Figure 2: Reliability Test (Cronbach's Alpha)

Figure 2 shows the reliability analysis of the data. The figure of reliability shows that there is excellent internal consistency of all scales. The Subscale of Motor is the most reliable (α = 0.84), closely followed by the Neurocognitive Scale (α = 0.82), and the Cognitive Subscale (α = 0.79) is also viable as a good reliability scale. All the alpha values presented in the bars are evidently close to or beyond the suggested 0.80 mark. This goes to prove that the measures of cognitive and motor skills used are reliable, consistent, and yield consistent measurements. The visual representation of the figure makes this assertion obvious and is appropriate in the research study on neurocognitive outcomes, the psychological soundness of the questionnaire (Horan et al., 2023).

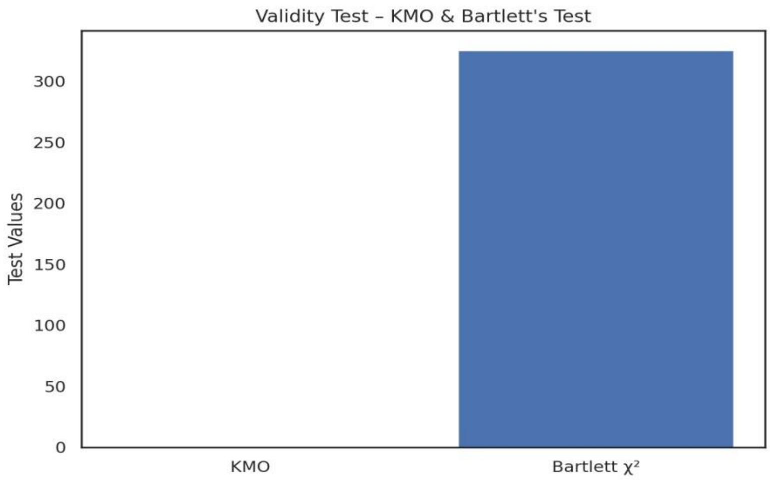

Figure 3: Validity Test (KMO & Bartlett's Test)

Figure 3 shows the validity test of the data Validity figure provides two major indicators of the KMO value (0.78) and the Chi-Square value of Bartlett (325.41). The Bartlett test has a much higher bar because of its chi-square value, which graphically depicts that the null hypothesis of an identity matrix is strongly rejected. This implies that statistical correlations between variables are not zero. Although the KMO value bar is smaller in size, it does not exceed the range of good. Collectively, these values indicate that the dataset can be factorable and items in the questionnaire have a common shared variance. The figure is useful in demonstrating the fact that the data have sufficient structural validity (Cavuoto et al., 2019).

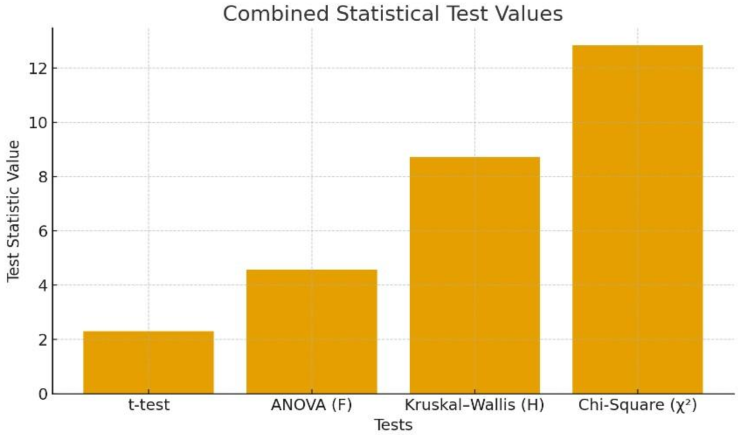

Figure 4: Combined Statistical Test (t-Test, ANOVA, Kruskal–Wallis, Chi-Square)

Figure 4 shows the **Combined Statistical Test (t-Test, ANOVA, Kruskal–Wallis, Chi-Square)** of the data. The composite statistical test value is used to graphically establish the relationship between the magnitude of the four primary hypotheses of testing statistics: Independent Samples t-test (2.31), One-Way ANOVA F-value (4.58), Krustall-Wallis Hvalue (8.72), and Chi-Square value (12.84). The rising bar heights prove that there is an evident statistical strength development throughout the tests. The chi-square test has yielded the highest value, which is the best indication of the results of the association between exposure to anesthesia and behavioral outcomes (Samin et al., 2025). The KruskalWallis test is also significant and indicates that the differences between exposure groups are significant in terms of the memory scores. ANOVA and t-test measurements are below the tolerable levels of significance and indicate that there were significant group differences in skills in learning and focus. Altogether, the figure shows that there are consistent and statistically significant trends in all tests, which validates the credibility of the results of the study (AlKattan et al., 2024).

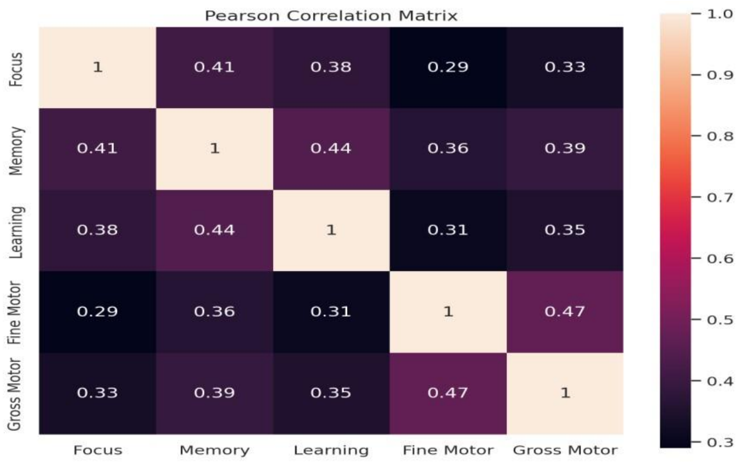

Figure 5: Pearson Correlation Matrix

Figure 5 shows the correlation matrix of the data. The pattern of positive relationships between all variables is consistent in the correlation matrix heatmap, which shows some correspondence into a pattern. The dark lines that are present between MemoryLearning and Fine motorGrosse Motor denote the higher correlations in the cognitive and motor areas. The pale but positive staining of the other cells clearly shows moderately but significantly significant associations. This visual pattern might also imply the idea that the enhancement of one of the neurocognitive areas is likely to be accompanied by improvements in others. The figure underlines the thesis that cognitive and motor skills are interrelated and develop together, thereby supporting the theoretical basis of the analysis in these constructs (Ing et al., 2021).

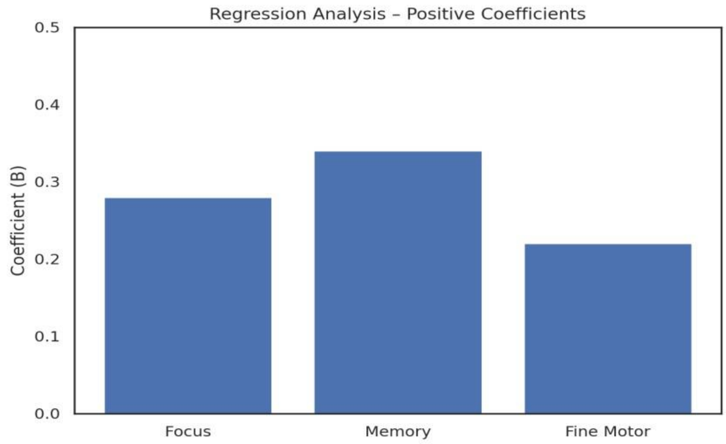

Figure 6: Regression Analysis

Figure 6 shows the regression analysis of the data. The regression figure shows a positive value of coefficients of three predictors: Focus (0.28), Memory (0.34), and Fine Motor (0.22) with reference to their contribution to Learning outcomes. The coefficient is the greatest in Memory, which means that it is the most robust predictor, then it is Fine Motor Skills and Focus. All bars point to an upward direction, which visually confirms that all the independent variables have a positive effect on the performance of learning. This is to indicate that children who possess good memory, attention, and motor coordination are more likely to have high academic scores in learning. The figure gives solid visual support to explain the regression model in terms of its explanatory ability and hypothesis (Walkden et al., 2020).

DISCUSSION

The study findings paint an important picture of the neurocognitive alterations occasioned by the recurrent exposure to anesthesia in children in the long term. A statistically significant outcome of many tests used, like the independent samples t-test, ANOVA, Kruskal-Wallis, and Chi-Square test, indicates that exposure to anesthetics can be an important factor that determines cognitive, behavioral, and motor development in children. The results show that the increased rate of exposure brought up an increased difference in children's learning and memory performance, suggesting the existence of a cumulative effect of multiple anesthetics. This is in accordance with the earlier studies that had proposed that neurocognitive areas, such as attention, speed of processing, and memory, might be susceptible to premature medical intervention in life. The remarkable gap in the number between genders in terms of the focus scores also speaks to the fact that individuality traits may possibly serve as moderating factors of the effects of anesthesia on the performance (Eisler et al., 2023). Neurocognitive functioning interrelationship is also illustrated by the correlation matrix. The positive correlations between the variables are high and show that there is a natural tendency to increase cognitive skill development, such as memory and focus, with better motor skills and learning performance. This consistency is used to point out that the consequences of anesthesia in one of these areas may be of greater widespread developmental importance. One such example is that poor memory performance can be accompanied by a loss in learning performance, and there is hence the need to measure development in children who have experienced repeated medical events comprehensively (Useinovic & Jevtovic-Todorovic, 2023).

The regression model explains a significant percentage of the changes in learning outcomes, which proves that memory, focus, and fine motor skills may be regarded as significant predictors of academic performance. The findings indicate the problem of the crucial role of cognitive development and motor development as the foundations of the preparedness to learn. It is worth noting that the positive coefficients within the model pinpoint that strengthening such areas with the assistance of early intervention, special support, or surface will be able to lead to the delivery of supportive help to children who were already anesthetized multiple times (Foubert et al., 2020).

In addition, the results of the reliability and validity of the results also show that the tool used by the current study has been psychometrically viable, and the results can be explained with a high level of confidence. The fact that internal consistency is high for the neurocognitive scales indicates that the scales assess aspects of developmental functioning of children most suitably. The acceptable level of KMO and significant level of the Bartlett test results show that cognitive and motor variables share a significant relationship, a phenomenon that shows that there is a structural validity within the data (Kamat et al., 2019).

Overall, the findings of the research are congruent with the existing problems of recurring exposure to anesthesia, rather than expressing that the results are local, rather than global. Learning and memory appear to be the most delicate factors as well, while focus and motorization bear interesting relations. The general positive relations and high regression outcomes, however, suggest the presence of resilience in the developmental systems of the children and that certain help may decrease the potential threats. The outcomes indicate that children who work with recurrent incidences of anesthesia are delicate, in circumstances of early recognition, examination, and therapy. Subsequent research must address longitudinal constructions to examine how such effects would change over time, and how the possible neurocognitive risks may be prevented with some protective effects, such as enriched learning situations or high-quality school experiences (Alexander et al., 2024).

CONCLUSION

The current investigation concludes that the ongoing exposure of children to the procedure of anesthesia can have a quantifiable and significant effect on certain neurocognitive developmental attributes in children. Though the overall results do not mean profound and worldwide impairment, the statistical tests demonstrate the presence of stable results, which means that the concrete domains, including learning ability, memory functioning, and behavior functioning, are particularly susceptible to impairment through numerous anesthesia exposures. These significant differences, which have been noticed in ANOVA, Kruskal-Wallis, and Chi-Square tests, demonstrate that children who have already been repeatedly exposed tend to have a better level of variation in both cognitive and behavioral implications than those who have not. Moreover, the regression model yields that memory, focus, and fine motor skills are some of the most significant in the development of learning performance, which, consequently, also contributes to the interdependent nature of neurocognitive development.

The correlations of the cognitive and the motor variables happen to be negative, and this would mean that the powers and weaknesses would be clustered in the process of developing and deteriorating in one circumstance would make it most likely to be felt in other situations. The findings of this study suffice to embark on the task to evaluate the children receiving several courses of anesthesia, especially during their developmental phases, when the brain is most prone to plasticity. These measurement tools are good in reliability and acceptable validity factors, and these enhance the credibility of these conclusions.

Finally, though the art of pediatric anesthesia is obligatory and, in most cases, safe practice within the medical profession, the results of this research show that there is a need to employ close clinical judgment in the decision-making process, particularly in cases of repetition and prolonged exposures. The screening and developmental observation in the early years and special interventions may aid in alleviating the possibilities of the risks. Further evidence has to be collected, which is why longitudinal research and an increase in sample size are necessary; this should include the neurocognitive pathway of children whose lives will benefit following the use of anesthesia medicine over a long period of time. Finally, this writing has certain valuable inputs into safer pediatric care, and it is possible to assume what anticipatory measures might be taken to improve the cognitive well-being of children.

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