

P300 Response Among Children with Down Syndrome: Age, Non- Verbal Intelligence and Social Maturity Effects.

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ABSTRACT:

Background

P300 of the event-related potential (ERP) component represents cognitive processing speed and the is associated with a deflection occurring at about 773-783ms. It is most frequently triggered in an "oddball" paradigm when a subject notices a random "target" stimulus among a routine train of typical stimuli. People with Down syndrome (DS) frequently exhibit prolonged P300 delay, which may indicate underlying neurocognitive impairment. Although there is increasing interest in the electrophysiological profiles of children with Down syndrome, little research has methodically looked at certain neurodevelopmental variables that predict P300 latency in this population.

Purpose

By addressing the above gap in the literature, the current study attempted to identify important neurodevelopmental correlates of cognitive processing speed in children with Down syndrome through investigating the predictive influence of age, nonverbal IQ, and social maturity on P300 latency.

Method

A cross-sectional design was employed with a purposively selected sample of 62 children with Down syndrome aged (5-

12) years. P300 latency was recorded using an auditory oddball paradigm using an evoked potential equipment. Non-verbal intelligence was assessed using Seguin Form Board test and Social maturity was evaluated using the Vineland Social Maturity Scale (VSMS). Descriptive statistics, and inferential statistics were used to analyze the data collected. IBM SPSS Statistics (Version 27.0) was used as software tool for data analysis.

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Results

In the first model, age did not significantly predict P300 latency. The explained variation increased significantly when nonverbal intelligence was included ($\Delta R^2 = .061$, $p < .05$). The final model explained 20.8% of the variance in P300 latency after social maturity was added, greatly improving the model ($\Delta R^2 = .094$, $p < .05$). Among the variables, social maturity turned out to be the most significant predictor.

Conclusion

The results imply that neuronal processing efficiency in children with Down syndrome is significantly influenced by cognitive and adaptive functioning rather than age. The significant impact of social maturity emphasizes the significance of functional and contextual elements in neurodevelopment, underscoring the necessity of comprehensive intervention strategies that address adaptive skills in addition to cognitive development.

Keywords: Down Syndrome, P300 latency, non-verbal intelligence, social maturity

1. Introduction

Down syndrome, the most prevalent genetic disorder associated with intellectual disability, is brought on by trisomy of chromosome 21. It is the most common non inherited “organic” cause of mental retardation¹. In addition to having a substantial impact on the child's development, the genetic abnormality of Down Syndrome (DS) also unknowingly affects important individuals in the child's life, such as parents, siblings, teachers, and friends. Variability in social adaptation among individuals with DS that cannot be explained by IQ alone is determined by the distinct profile of disabilities associated with DS, which includes both affective and cognitive aspects, interacting with contextual factors in the child's family, peer group, school, community, and culture²⁴. The emerging behavioural phenotype in individuals with Down syndrome includes a significant delay in nonverbal cognitive development², apart from particular deficits in speech, language production during infancy and childhood. A review of research on the cognitive characteristics of Down syndrome showed that relative deficiencies were consistently linked to

verbal working memory, morphological and syntactic processing, and expressive language, even though performance in most areas could be predicted based on overall intellectual disability^{1,21,30}.

Children with trisomy 21 show mild departures in neurotypically developing pathways which starts to appear early childhood and become noticeable by the time the child reaches school age¹. The linguistic deficiencies develop and persist and their nonverbal skills continue to progress according to the mental age³. Severe impairments in cognitive functioning and the ability to adapt to the demands of daily life that begin before the age of eighteen determines the characteristics of intellectual disability. Nonverbal abilities are said to be less negatively impacted, although subsequent research has revealed varying results based on which part of visuospatial cognition is taken into account²⁹. However, these people have fewer difficulties with adaptive behaviour than people with other cognitive disabilities². Area of social functioning which represents the ability of an individual to carry out daily tasks on their own is known as adaptive functioning, and it is commonly assessed using social maturity measurements²⁸.

Since social maturity has been shown to be associated with attentional involvement and cognitive processing efficiency^{18,19}, it may be linked to ERP indices such as P300 delay. Despite its therapeutic importance, the relationship between social maturity and electrophysiological markers in Down syndrome remains poorly understood.

The P300 (also called P3), one of the most studied ERP components, is typically activated by an oddball paradigm that incorporates rare deviant stimuli among common standard stimuli^{5,6}. Polich (2007) states that the P300 component's latency is a gauge of how quickly stimuli are assessed and how well cognitive processing works; shorter latencies signify quicker brain processing. Even when no discrimination response is needed, passive oddball paradigms (where participants ignore the stimuli or just listen) consistently elicit P300-like ERP components that are comparable in latency to active tasks, making them helpful in populations incapable of performing active tasks^{6,7}. In children with Down syndrome, atypical neurodevelopment affects both structural brain growth and functional cognitive processing. P300 latency reflects the speed of cognitive processing and neural efficiency during stimulus evaluation and decision-making⁹. Passive oddball paradigms are especially suitable for children with Down syndrome because they require minimal task compliance and reduce the effect of motivation, language, and executive demands on ERP outcomes. Henceforth, examining P300 latency delay during passive listening is a valid and developmentally appropriate method of evaluating cognitive processing efficiency in this population. Furthermore, there has been an increase in interest in neurophysiological tests that provide objective indicators of cognitive processing with little task and language demands. Event-Related Potentials (ERPs) are produced from electroencephalographic (EEG) recordings and offer millisecond-level temporal precision, making them perfect for studying cognitive processing in clinical and developmental populations¹³.

Developmental studies have demonstrated age-related decreases in P300 latency, demonstrating the maturation of attentional and cognitive control systems between childhood and adolescence^{10,11,12}. Children with Down syndrome frequently show greater P300 latency when compared to peers who are typically developing, indicating delayed brain processing and reduced cognitive efficiency^{12,14,45}. However, there is a great deal of heterogeneity in the DS children, suggesting that individual differences in biological, cognitive, and adaptive characteristics may affect electrophysiological responses. For children with Down syndrome, nonverbal intelligence tests are particularly crucial since they provide a more accurate assessment of underlying cognitive ability with lower language needs.

One of the main consequences of Down syndrome is a delay in cognitive development¹⁸. However, young infants with Down syndrome can exhibit empathy and affection despite this cognitive delay²⁴, which results in the need to investigate the mutual influences between these social and cognitive domains in order to comprehend distinct developmental outcomes. This investigation evaluates the extent to which chronological age, cognitive ability, and adaptive functioning uniquely account for variance in neural processing efficiency, thereby emphasizing the need to move beyond rigid, one-dimensional developmental labels.

The present study is informed by the Transactional Model of Development, proposed by Arnold J. Sameroff, which emphasizes the dynamic interaction between biological and environmental influences in child development. According to this framework, developmental outcomes are not solely determined by genetic or biological maturation but emerge from continuous interactions between the individual and the environment²³. Also, it postulates neurological, psychological, and social development as dynamic processes resulting from ongoing interactions between the child and his or her environment which serves as the foundation for the current investigation. In children with Down syndrome,

neurodevelopmental characteristics interact with cognitive and adaptive functioning, which may influence neural information processing as reflected in event-related potentials such as the P300 component.

While we know that Down syndrome affects P300 latency, the exact developmental and cognitive mechanisms behind these differences remain unclear. In light of this, the current study was carried out to methodically examine the independent and combined effects of age, non-verbal performance ability and social maturity on P300 latency elicited using a passive auditory oddball paradigm in children with Down syndrome. The purpose of this study is to gain insight at cognitive, and adaptive behaviour factors that predict P300 latency in children with Down syndrome through answering the following research questions

1. Does a child with Down syndrome's P300 latency largely depend on their age?
2. Is P300 latency influenced by nonverbal intelligence beyond age?
3. Does social maturity provide additional predictive value in explaining variability in P300 latency?

Methods Sample size

It was guided by Green's (1991) recommendations for regression ($N \geq 50 + 8k$) and Cohen's (1988) criteria for statistical power ($\alpha = 0.05$, power = 0.80 with medium effect size). The current study comprised a clinical population of children with Down syndrome, where participant availability is fundamentally constrained, even if the recommended sample size for multiple regression based on Green's guideline was not entirely obtained. As a result, purposive sampling was used, and accessibility and feasibility were taken into consideration while determining the final sample size. Previous neurophysiological investigations involving particular groups have revealed similar sample sizes (773-783). Despite this limitation, the sample was judged adequate to explore the relationships between variables and provide a preliminary understanding of P300 delay predictors.

Research Design and Participants

A cross-sectional observational design was adopted in a sample of children with Down syndrome aged 5–12 years recruited from genetic and metabolic clinic, Department of Paediatrics, Institute of Medical Science, Banaras Hindu University, Varanasi. The study included children with a confirmed diagnosis of Down Syndrome (DS) with normal hearing or corrected (hearing with or without visual aid) and having non-verbal communication while excluding those with comorbid neurological disorders (like epilepsy), other neurodevelopmental disorders (like Attention deficit/hyperactivity disorder, Autism, communication disorders etc), severe sensory impairments, any social skill or cognitive training and any current psychoactive medication use. Parents and guardians were provided written informed consent, but whenever possible, assent was also acquired. Participants' comfort, willingness, and behavioural cues were closely watched if they were unable to give meaningful assent because of cognitive difficulties related to Down syndrome. Any signs of discomfort or refusal led to immediate discontinuation of the procedure.

Measures

Non-verbal Intelligence

The Seguin Form Board Test (SFBT) was used to evaluate nonverbal intelligence. Seguin created a straightforward performance-based IQ test in 1856 that used form boards to assess nonverbal cognitive ability, eye-hand coordination, shape concept, and visual perception. It can be applied to youngsters and stays used to evaluate the participants' motor dexterity, visuomotor coordination, spatial organization, and performance speed and accuracy. The child was supposed to swiftly and precisely fit matching geometric blocks into slots on a wooden board in order to pass this test. An index of nonverbal intellectual functioning is obtained by scoring performance based on accuracy and completion time. The SFBT has proven to be reliable in Indian

contexts as it lowers linguistic and cultural demands²⁹. The intelligence quotient (IQ) was calculated using the best time from three trials to obtain a mental age from the standard chart in the manual⁴⁴.

Intelligent quotient (IQ) is then calculated as:

$$IQ = MA/CA \times 100$$

Where:

MA = Mental Age (best time out of three trials as given in manual)

CA = Chronological Age (actual age in months/years)

Social Maturity

Social maturity was assessed using Vineland Social Maturity Scale (VSMS) that evaluated social functioning yielding Social Quotient (SQ). To obtain the social age, the raw score is converted to social age using tables and charts provided in the VSMS manual³¹. The VSMS has been widely utilized in India as a culturally sensitive instrument for evaluating social maturity and adaptive behavior in people with intellectual disabilities⁴³. Social age (SA) represents the age level at which the individual's social skills are typically observed. Each item is scored as "Yes" (1) if the child can perform the behavior, or "No" (0) if not. Scores are added across items in each domain → raw scores. These raw scores are then converted into a social age (SA) using standard norms.

Social quotient (SQ) is then calculated as:

$$SQ = SA/CA \times 100$$

Where:

SA = Social Age (from scale)

CA = Chronological Age (actual age in months/years)

Demographic Variables

Age (in years) and gender (male/female) were recorded using data obtained from participants case information sheets and hospital records.

ERP Recording

Electroencephalography (EEG) data was recorded using a standard Event-Related

Potential (ERP) system, (NEUROSTIM -NS2 MEDICAID) with electrodes positioned according to the international 10–20 system. Participants were instructed to lie comfortably on the patient bed and were allowed to maintain a passive state throughout the recording session. To maintain the impedance of below 5kΩ, the participants forehead was cleaned with spirit, post which disposable gel based paediatric electrodes (25mm) was placed at Cz as active electrode, at left and right mastoid processes and grounding was done at Fpz site. Thereafter electrode leads were connected and the recording was initiated once stable signal quality was attained and was monitored through display screen. Auditory stimuli consisted of frequent standard tones (i.e., 1000 Hz; 80%) and rare tones (i.e., 2000 Hz; 20%), presented binaurally through paediatric headphones. The P300 component was identified as the largest positive peak appearing at 300 ms post-stimulus at midline electrode site (at Cz)⁴. P300 latency to rare stimuli, averaged across two trials, was used in the data analysis.

Procedure

After obtaining informed consent from parents, P300 testing was conducted in a single session in a dimly lit sound attenuated room of Brain Evoked Response Audiometry (BERA) laboratory, of Department of Physiology, Institute of Medical Sciences. This was followed by data collection related to Anthropometric measures which was then followed by IQ measurement. The social maturity questionnaire was interviewed to parents concurrently. The entire session lasted approximately 2 hours.

Ethical Considerations

The Institutional Ethics Committee approved the study. Each procedure followed the ethical guidelines for studies concerning children with intellectual disabilities.

Study Variables

The independent variables are organized into three conceptual blocks:

- a. Biological Factor (Age as control variable)

- b. Cognitive Factor (Non-verbal intelligence)
- c. Social maturity (Adaptive behaviour)

of Neural processing which is conceptualised through flow chart as represented below:

The effect of the aforementioned variables taken as predictors shall impact the Outcome Variable

Figure 1: Predictors of P300 Latency in children with Down Syndrome

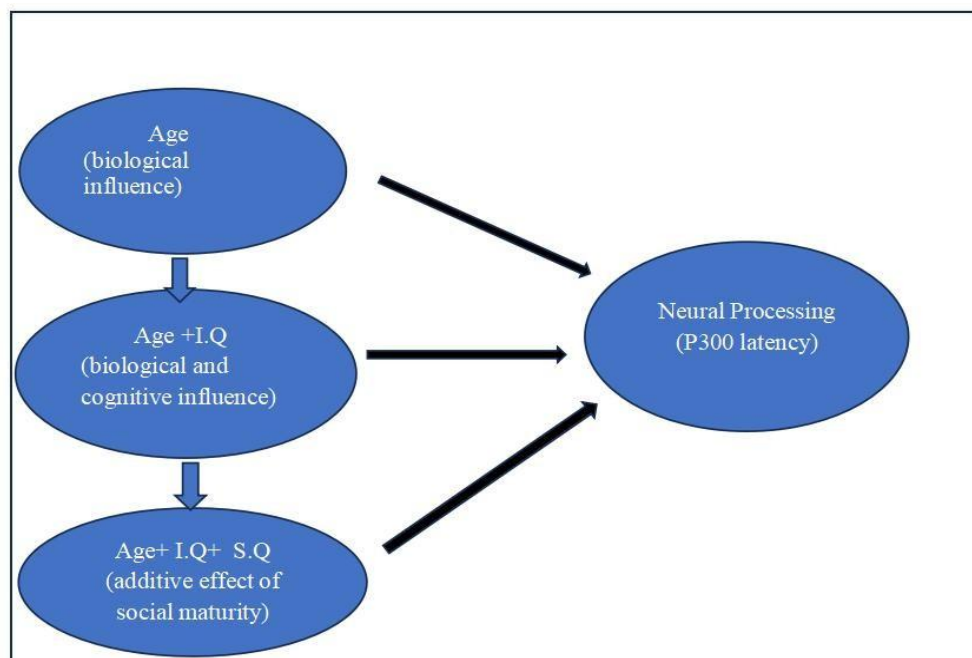


Figure 1 shows a conceptual model demonstrating layers of development interdependently shaping neural processing in Down Syndrome

Statistical Analysis

All variables were subjected to descriptive statistics. After ensuring that the data had a normal distribution, (using Shapiro-Wilk test) confirming the normal distribution of the data, to look at bivariate correlations between predictors and P300 latency, a hierarchical multiple regression analysis was used to model the relative contributions of each predictor to P300 latency. In the first block, biological factor of age was entered as control variable. In the second block, non-verbal intelligence and thereby social maturity was entered to examine

their incremental contribution to the prediction of P300 latency in children with Down syndrome. SPSS software version 27.0 was used for data analysis.

Results

The effects of age, social maturity, and nonverbal IQ on P300 latency in children with Down syndrome were investigated using a hierarchical multiple regression analysis. The following Hierarchical regression model structure was considered for interpretation.

Model 1: Biological factor

Age ➡ P300 latency

Model 2: Biological and cognitive factors

Age + I.Q ➡ P300 latency

Model 3: Biological, cognitive and adaptive factors

Age + I.Q + S.Q ➡ P300 latency

Table 1: Hierarchical Regression Analysis of Predictors of P300 Latency

Predictors	Model 1	Model 2	Model 3
Age	-.0230 (.085)	-.0222 (.083)	-.0226 (.0793)
IQ	-	-.0247 * (.023)	-.0218 (.0222)
S.O	-	-	-.0307 *(.0197)
R ²	.053	.114	.208
ΔR^2	.053	.061*	.094*
F change	3.366	4.056	6.852
P value	.072	.049*	.011*

Note: * $p < 0.05$; parentheses () represent standard error

In the above table, using hierarchical regression analysis, the effects of age, social maturity, and nonverbal intelligence (IQ) on P300 latency ($N = 62$) were examined. Model 1 entered age, Model 2 entered non-verbal intelligence (IQ), and Model 3 entered social maturity. For each model regression coefficients (β) were presented. There was no meaningful prediction of P300 delay by Model 1. When IQ was included to Model 2, the explained variation significantly increased ($\Delta R^2 = .061$, $p < .05$). Model 3's final model explained 20.8% of the variance in P300 delay after social maturity was added (ΔR^2

$= .094$, $p < .01$). For significant predictors, the 95% confidence intervals did not contain zero, suggesting reliable effects.

The final model's Durbin–Watson statistic was 2.277, implying that the assumption of independence of errors was satisfied, showing no signs of autocorrelation.

Discussion

The current study investigated the predictive role of age, non-verbal intelligence (IQ), and social maturity (SQ) on P300 latency in children with Down syndrome using hierarchical regression analysis.

Age was entered in the first step of the regression model to assess its predictive value for P300 latency. Age contributed 5.3% of the variance in P300 delay in the first model, although this was not statistically significant ($p = .072$). This implies that among children with Down syndrome, age alone is not a significant

predictor of cognitive processing speed. In contrast, P300 latency often decreases with age, indicating maturation of cognitive processing^{35,36} The abnormal neurodevelopmental trajectory seen in Down syndrome⁷⁷³⁻⁷⁸³, which is marked by delayed brain maturity and decreased neuronal efficiency, may be the reason for the study's lack of significance. This confirms earlier research suggesting that in neurodevelopmental problems, functional brain maturation may not be closely correlated with chronological age^{40,41}

In the second step, the explained variation jumped significantly from 5.3% to 11.4% ($\Delta R^2 = .061$, $p = .049$) when IQ was added to Model 2. This suggests that beyond age, IQ has a major role in determining P300 latency. Studies have reported a negative relationship between P300 latency and IQ tests in both neurotypical individuals and case group^{15,16}. Based on this premise, the neural efficiency model postulates that individuals with higher levels of cognitive functioning process information more efficiently, needing less time and neural resources¹⁵. This finding is in accordance with earlier studies indicating shorter P300 latency and faster stimulus appraisal are linked to higher cognitive capacity⁵. P300 is commonly regarded as an indicator of working memory updating and attention allocation, both of which are strongly associated with cognitive functioning^{6,42}. IQ seems to be a more sensitive predictor of brain processing efficiency than age in children with Down syndrome, whose cognitive capacities vary greatly.

When social maturity was inserted to Model 3, the explained variance increased significantly and statistically significantly ($\Delta R^2 = .094$, $p = .011$), reaching 20.8% of the overall variance.

This suggests that P300 delay can be strongly and independently predicted by social maturity.

This study is especially significant since it emphasizes how functional and adaptive behaviour affects neurophysiological processes. A person's capacity to interact with their surroundings, carry out everyday tasks, and react to social expectations is a measure of their social maturity. This finding supports the with Arnold Sameroff's Transactional Model of Development, a developmental theory, holds that ongoing interactions between an individual and their surroundings impact cognitive development 23.

Limitations and Strength

Longitudinal studies are needed to examine developmental changes in P300 latency over time. The final model explained only 20.8% of the variance in P300 latency, indicating that other unmeasured neurobiological factors may play a significant role. Despite these limitations, the study offers important preliminary insights into the neurocognitive and adaptive predictors of P300 latency in children with Down syndrome. The small sample size and cross-sectional design are the key limitations, affecting generalizability and causal interpretation. Longitudinal studies with larger sample are recommended to examine developmental trajectories of P300 latency and to better understand how cognitive and social factors influence neural processing over time. Further studies should explore multiple dimensions of adaptive behaviour, including conceptual, social, and practical domains, rather than relying on a single global social maturity score along with gender variation in P300 response with respect to cognitive ability and adaptive behaviour measures.

Conclusion

The conclusion drawn from above findings reveal that biological age does not significantly

predict P300 latency in children with Down syndrome; nevertheless, non-verbal intelligence and social maturity played a vital role, with social maturity appearing as the best predictor. Age has little prognostic value. Cognitive capacity is a major factor.

The current research shows that within context of Down syndrome, development depends on more than just age. The findings also point to the fact that P300 latency could be a biomarker of cognitive and adaptive functioning. Interventions aimed at developing social skill may indirectly increase the effectiveness of cognitive processing emphasizing the value of comprehensive rehabilitation techniques rather than concentrating only on IQ or age. Thus, we conclude emphasising on combining electrophysiological measure, behavioural assessment and cognitive test for provide a more holistic understanding of Down Syndrome child's developmental changes.

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Consent to Participate

The author confirms that informed consent was obtained from all participants' caregivers prior to data collection. They were informed about the purpose of the study, confidentiality of their responses, and their right to withdraw at any time. In addition, assent was obtained from the children in an age-appropriate manner, respecting their level of understanding and willingness to participate in the study. No identifying information has been reported in the manuscript.

Statement of Ethics

The study protocol was approved by the Research Ethical Committee of the Institute. Name of ethics committee: Institute Ethical Committee, Banaras Hindu University.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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Data availability statement

The data used to support the study's conclusions were obtained from patient recordings and responses from standardized questionnaires. These data are not accessible to the general public in compliance with Institutional Ethics Committee regulation and to safeguard patient privacy. Upon reasonable request and with prior

Institutional Ethics Committee approval, de-identified data may be received from the corresponding author.

ICMJE Statement

All authors contributed equally to the following:

1. Substantial contributions to the conception, design, data acquisition or analysis and interpretation.
2. Drafting and revising.
3. Final approval for publication.
4. Agreement to be accountable for all aspects of the work.

Use of Generative AI

No generative AI tools were used in the preparation of this manuscript.

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