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Original Article

Perception of Pitch and Duration Pattern of Vowel /a/: A Comparison across Age and Gender in 5 to 9 Years Old Children

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Abstract

Objectives The present study aimed to develop pitch pattern test (PPT) and duration pattern test (DPT) using vowel and investigate the temporal ordering skills among typically developing children aged 5 to 9 years across genders. The study compared the performance of children on these tests across different age groups and gender. The study also investigated the relationship between performance on the DPT and PPT tasks using the vowel /a/.

Materials and Methods Two verbal stimuli tests, DPT and PPT, were developed. For DPT, the vowel /a/ was used at 246 Hz and had two different durations of 500 and 250 ms for long and short stimuli, respectively, with a 300-ms interstimulus interval. For PPT, the vowel /a/ was used at 220 Hz for “low” stimuli and 261 Hz for “high” stimuli, both lasting 500 ms, with a 300-ms interstimulus duration and a 6-second intersequence duration.

A cross-sectional study design was utilized in the study. A total of 100 typically developing school children aged between 5 and 9 years were divided into five age groups, each consisting of 10 males and 10 females. All children passed a hearing screening at 25 dB HL from 250 Hz to 4,000 Hz and had an average or above-average academic performance as reported by their teacher. All the children were tested using the developed tests. The order of administration of DPT and PPT was randomized. Children were instructed to listen to the sequence of vowel presentations and hum them in the same order.

Results There was no significant difference between scores of males and females across all the age groups. On both tests, there was a significant improvement in the performance of the children with increase in age. There was a strong overall correlation between scores of DPT and PPT.

Conclusion Both DPT and PPT, utilizing vowels as stimuli, did not exhibit a ceiling effect. This study highlighted a robust correlation between the two tests.

Keywords
- duration
- pitch
- ordering
- vowel
- tone
- temporal processing
- children

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Introduction

Auditory temporal ordering refers to the ability to accurately perceive multiple auditory signals in their precise order of presentation.[1] Since the dynamic acoustic changes in fluent speech play a facilitatory function in the extraction of meaning, temporal ordering is thought to be crucial for speech recognition.[2] Auditory temporal ordering is generally measured using pattern sequencing stimuli. In comparison to the detection of auditory events, these stimuli are considered to be more complex as they assess the processes of pattern discrimination, temporal ordering, and labeling.[3] The most widely used clinical tests of temporal ordering, which gained widespread acceptance, are the pitch pattern test (PPT) and the duration pattern test (DPT).[4] Out of these two, PPT is known for tapping the processes of frequency discrimination, temporal ordering, and linguistic labeling.[3] Literature have revealed that the PPT is resistant to peripheral hearing loss as long as the stimuli are audible and is sensitive to lesions of the cerebrum, the corpus callosum, and the brainstem.[5,6] The DPT also assesses the processes of duration discrimination, temporal ordering, and linguistic labeling[1] and is sensitive to cerebral lesions.[7] Indeed, the DPT has been regarded as a more demanding task in comparison to the PPT. Moreover, at all ages, the normal cutoff scores for the DPT are found to be lower than those for the PPT.[3]

Temporal patterning tasks involving linguistic labeling of tonal stimuli have been identified as valuable tools for assessing the neuromaturation of the corpus callosum in the pediatric population.[3,8,10] Furthermore, temporal ordering scores in children, both in PPT and DPT, are reported to improve with increasing age.[11–13] On the other hand, temporal ordering abilities are often observed to have deviant scores in children with auditory processing disorder.[11,14] These analogous findings have also been reported among children with stuttering,[15,16] speech sound disorders,[17] as well as among children with dyslexia,[18] indicating the existence of temporal ordering deficits in these pediatric population.

In the literature, the temporal ordering task irrespective of whether it is PPT or DPT, has most often been reported using tonal stimuli.[1,12] Some investigators have also explored the use of verbal stimuli for the same.[19,20] Jutras and Gagné proposed the task of sequencing using verbal (/ba/ and /da/) and tonal stimuli (1,000 Hz pure tone and wideband noise) in children with and without hearing loss. The finding suggested that the children with hearing loss had more difficulty in recalling verbal sequences than nonverbal sequences.[21] The observed difficulty in recalling the verbal stimuli could have resulted from the phonological similarity effect, which arises when similar-sounding speech sounds are used and can impede pattern recognition compared to nonverbal sounds that are dissimilar acoustically.[22] Therefore, these deficits in the auditory sequential organization were reported to be closely related to the presence of auditory perceptual processing deficit. Similar findings have also been reported by other investigators.[1] These tests on patterning verbal blocks[19,22–24] often demand linguistic proficiency of a certain level. However, when compared to tonal stimuli, these verbal blocks may demonstrate a greater degree of naturalness in relation to speech sound. Thus, it may be preferable to utilize simpler verbal stimuli such as vowels for temporal ordering tasks, as they are not limited in their usage by the language of the subject or examiner and could easily be administered among children. Recent literature on PPT using the vowel /a/ in adults[25] also reported the usage of vowel /a/ at 220 and 261 Hz, corresponding to the musical notes A3 and C4, respectively. Each vowel lasted 150 ms, with an interstimulus interval of 200 ms and an intersequence interval of 6 seconds. The study indicated that younger adults achieved notably higher mean scores compared to middle-aged and older adults. However, similar studies have never been done on children. Further, there is a need to understand the maturational effect on the performance of PPT and DPT using vowel among children. Considering the use of a relatively longer duration of vowels and intersequence intervals for children,[10] the present study aimed to develop the PPT and DPT using vowel and investigate the temporal ordering skills among typically developing children aged 5 to 9 years across genders. The study compared the performance of children on these tests across different age groups and gender. The study also investigated the relationship between performance on the DPT and PPT tasks using the vowel /a/.

Materials and Methods

The present study was approved by the research advisory committee of the institute. The research received ethical approval from the Institutional Ethics Committee (Ref. BVDUMC/IEC/40, dated June 30, 2021). The present study employed a cross-sectional study design with purposive sampling to collect data in the school setting.

Development of Duration Pattern Test Using Vowel

The DPT using vowel /a/ was developed using the Praat software version 6.1.16.[26] The voice of a 25-year-old female was utilized to record the vowel /a/ in a sound-treated room (ANSI S3.1-1991(R2003)) using a Lenovo ThinkPad E14 and insert phones Bassheads 225 (boAt) at a sampling rate of 44,100 Hz. The recorded vowel /a/ was further manipulated to vowel with the fundamental frequency of 246 Hz, which corresponds to the B3 musical note. A panel of five experienced audiologists, each with normal hearing and over 5 years of professional experience, was tasked with evaluating the quality of both original and modified auditory stimuli. The assessment was conducted using a three-point rating scale: 1 for intelligible, 2 for intelligible but requiring adjustment, and 3 for not intelligible. Both stimuli received a score of 1, indicating 100% intelligibility. Audacity software version 2.1.3 was used to prepare 15 normalized test items using these stimuli. Normalization adjusted the gain of the stimulus to achieve a target amplitude, ensuring consistent loudness across test items without compromising quality or altering the signal-to-noise ratio. Further, each test item included two different vowel durations of 500 and 250 ms with an interstimulus interval of 300 ms to prepare six different combinations of three vowel contour DPT (Short Short Long, Long Long Short, Short Long Short, Long Short Long, Long Short Short, Short Long Long).[7] Normalization was done for all patterns of DPT with a calibration tone at 1,000 Hz for 30 seconds.

Development of Pitch Pattern Test Using Vowel

The PPT using vowel /a/ was developed using the Praat software version 6.1.16.[2] The voice of a 25-year-old female was used to record the vowel /a/ in a sound-treated room (ANSI S3.1-1991(R2003)) using a Lenovo ThinkPad E14 and insert phones Bassheads 225 (boAt) at a sampling rate of 44,100 Hz. The fundamental frequency of the recorded voice was 243 Hz. This fundamental frequency was modified to 220 Hz to obtain "low /a/" and 261 Hz to obtain "high /a/" corresponding to A3 and C4 musical notes, respectively. A group of five audiologists, all with normal hearing and over 5 years of experience in the field, assessed the quality of both recorded and manipulated stimuli using a rating scale consisting of three points (1-intelligible, 2-intelligible but requires adjustment, 3-not intelligible). Each of the stimuli received a score of 1, indicating a complete intelligibility rate of 100%. Further, Audacity software version 2.1.3 was used to prepare 15 normalized test items using these stimuli. Each test item included three vowels of 500 ms each with an interstimulus duration of 300 ms and an intersequence duration of 6 seconds.[9] The test items resulted in six different combinations of three vowel contour PPTs (Low Low High, High High Low, Low High Low, High Low High, High Low Low, Low High High). Normalization was done for all patterns of PPT using a calibration tone at 1,000 Hz of 30 seconds.

Administration of the Test

The present study considered a total sample size of 100 typically developing school-going children, considering an effect size (f) of 0.5, a type I error probability (α) of 0.05, and a test power ($1-\beta$) of 0.95 for five different groups using G*Power 3.1.9.7. None of these children had a known history or presence of any relevant middle ear pathology. None of them had any vestibular dysfunction, neurological problem, or radiological abnormality related to hearing, speech, language, and/or cognition. Based on their age, these children were further divided into five groups that included group I (5–5.11 years), group II (6–6.11 years), group III (7–7.11 years), group IV (8–8.11 years), and group V (9–9.11 years). Each of these age groups consisted of 10 male and 10 female participants. All of these children passed a hearing screening conducted at 25 dB HL from 250 to 4,000 Hz. The academic performance of all the children was average or above average as reported by the teacher. Further, Screening Checklist for Auditory Processing developed by Yathiraj and Mascarenhas[27] was performed and all the children had a score of less than six.

To administer the tests, all the participants were randomly administered with the DPT using vowel test followed by the PPT using vowel test and vice versa. Two separate trial runs were performed for both tests. Participants were instructed to respond in humming mode for both tests. All the test procedures were carried out in a quiet room with adequate lighting. Children were seated at a distance of 1 feet from the laptop placed at 0-degree azimuth. The stimuli were presented through a laptop whose output was calibrated to ensure that stimuli are presented at 60 dB SPL. For both tests, initially, the practice trials were given for familiarization to ensure that the participant understood the instruction. This was followed by the presentation of 15 test stimuli in each test.

In the case of the DPT using vowel, children were instructed to listen to the duration sequence of vowel and hum it in the same order. Similarly, in the case of the PPT, children were instructed to listen to the pitch sequence of vowel and hum it in the same order. For both tests, each triad of stimuli repeated in the correct sequence was assigned a score of "1." On the other hand, any other responses were assigned a score of "0." These responses were recorded in written form. Omission and order inversion were considered incorrect in both tests.

Statistical Analysis

The IBM Statistical Package for Social Sciences (SPSS) version 23 was used for the statistical analysis of the data. Shapiro–Wilk test of normality revealed that the data has nonnormal distribution ($p < 0.05$). Therefore, the Mann–Whitney *U* test was performed for both tests to investigate if there is a difference in the performance of males and females. Further, the Kruskal–Wallis H test was performed to examine the effect of age on the performance of DPT and PPT using vowel. It was followed by post hoc analysis using the Mann–Whitney *U* test. Kendall Tau correlation was performed to investigate any relationship between the DPT and PPT using vowel /a/.

Results

In the present study, the response rate was determined based on the percentage of correct scores out of 15 stimuli presented. Among the children in group I, the response rates, the number of children who could perform the test, for DPT and PPT using vowels were 45 and 50%, respectively. In the case of group II, the response rate was found to be 65% for both tests. Among the children in groups III, IV, and V, there was a consistent upward trend in the response rate for both tests, eventually reaching 100%. Mann–Whitney *U* test was utilized to compare the scores of both tests among different age groups based on gender.

It can be noted from ►**Table 1** that there was a little variation in the scores of males and female across different age groups for the DPT using vowel /a/. But the Mann–Whitney *U* test revealed no significant gender difference in the scores of any of the age groups ($p > 0.05$). Similarly, as shown in ►**Table 2**, there was no significant difference between the scores of males and females for PPT using the vowel /a/.

To further analyze the data, descriptive statistics were performed to examine the scores of the DPT and PPT using vowel /a/ across five different age groups as depicted in ►**Fig. 1**. Observably, the scores for both tests exhibited a consistent upward trend as age progressed from 5 to 9 years.

Table 1 Comparison of the scores of duration pattern test across gender and age groups

Age groups	Gender	Mean	SD	Median	Interquartile range		Mann–Whitney *U* test	
					Q1	Q3	*Z*	*p*
Group I (5 to 5.11 years)	Male	0.60	0.97	0.00	0.00	1.00	0.83	0.48
	Female	1.20	1.48	0.50	0.00	2.25		
Group II (6 to 6.11 years)	Male	2.90	1.79	3.00	1.50	4.25	0.97	0.35
	Female	1.90	2.38	3.50	0.00	4.25		
Group III (7 to 7.11 years)	Male	4.10	1.10	4.00	3.75	4.00	0.16	0.91
	Female	4.50	1.71	4.00	3.00	6.00		
Group IV (8 to 8.11 years)	Male	5.70	1.49	5.50	4.75	6.25	0.88	0.44
	Female	5.10	0.74	5.00	4.75	6.00		
Group V (9 to 9.11 years)	Male	6.50	2.71	6.00	4.75	9.00	0.99	0.35
	Female	7.50	2.46	7.00	5.00	10.00		

Abbreviation: SD, standard deviation.

Table 2 Comparison of the scores of pitch pattern test across gender and age groups

Age groups	Gender	Mean	SD	Median	Interquartile range		Mann–Whitney *U* test	
					Q1	Q3	*Z*	*p*
Group I (5 to 5.11 years)	Male	0.90	1.29	0.50	0.00	1.25	0.85	0.44
	Female	2.10	2.28	1.50	0.00	4.25		
Group II (6 to 6.11 years)	Male	4.60	2.63	3.00	3.75	6.25	1.68	0.11
	Female	2.30	2.67	2.50	0.00	5.25		
Group III (7 to 7.11 years)	Male	5.00	0.82	5.00	4.00	6.00	0.16	0.91
	Female	5.00	0.94	5.00	4.00	5.25		
Group IV (8 to 8.11 years)	Male	6.90	2.33	6.00	5.75	7.25	1.04	0.35
	Female	5.90	0.74	6.00	5.00	6.25		
Group V (9 to 9.11 years)	Male	8.30	3.16	7.00	6.50	9.00	0.91	1.00
	Female	7.70	1.50	7.00	6.75	9.25		

Abbreviation: SD, standard deviation.

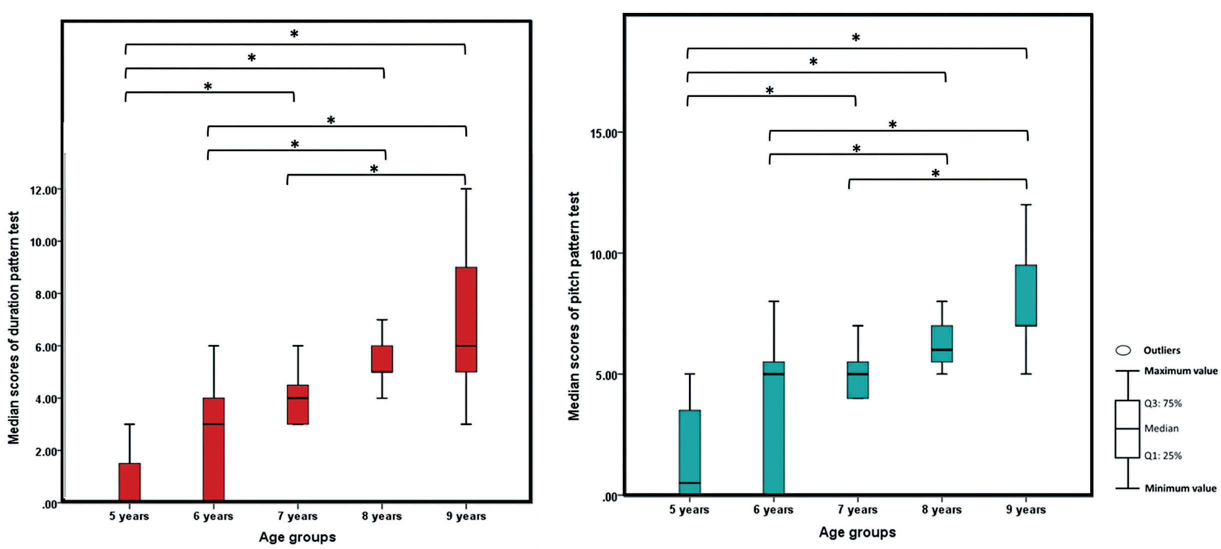

Fig. 1 Pictorial representation of the median scores of duration pattern test and pitch pattern test using vowel /a/ using the box plot. (**A**) The median and interquartile range of duration pattern test using vowel /a/. (**B**) The median and interquartile range of pitch pattern test using vowel /a/. The pairwise comparison across age groups is illustrated with * when a significant difference was observed.

However, it was noticeable that the interquartile range for each group increased as the age range expanded for both tests (►**Supplementary Table S1**).

Furthermore, the Kruskal–Wallis H test was conducted to compare the scores among different age groups for both the tests. The results revealed a significant main effect of age groups for DPT (χ^2 (4) = 62.69, $p < 0.001$) and PPT (χ^2 (4) = 60.96, $p < 0.001$) with vowel /a/. Hence, post hoc analysis was performed using the Mann–Whitney U test to understand the interaction between the age groups for both tests. The results of the test revealed significant differences between several age groups. For the DPT using vowel, group I revealed a significant difference in the scores with that of group III ($U = 34.58$, $Z = 3.81$, $p = 0.001$), group IV ($U = 51.98$, $Z = 5.73$, $p < 0.001$), and group V ($U = 61.90$, $Z = 6.82$, $p \leq 0.001$). Similarly, a significant difference was found in the scores of group II with that of group IV ($U = 36.18$, $Z = 3.99$, $p = 0.001$) and group V ($U = 46.10$, $Z = 5.08$, $p \leq 0.001$). Also, such a significant difference was observed in the scores between group III and group V ($U = 27.33$, $Z = 3.01$, $p = 0.03$). For the PPT using vowel, group I revealed a significant difference in the scores with that of group III ($U = 28.08$, $Z = 3.11$, $p = 0.019$), group IV ($U = 49.05$, $Z = 5.43$, $p < 0.001$), and group V ($U = 63.75$, $Z = 7.05$, $p \leq 0.001$). Similarly, a significant difference was found in the scores of group II with that of group IV ($U = 29.43$, $Z = 3.26$, $p = 0.011$) and group V ($U = 44.13$, $Z = 4.88$, $p \leq 0.001$). Also, such a significant difference was observed in the scores between group III and group V ($U = 35.68$, $Z = 3.95$, $p \leq 0.001$). None of the other comparisons were significant ($p > 0.05$).

Further, the correlation of the scores between the DPT and PPT using vowel /a/ was performed using the Kendall Tau-*b* coefficient. It was found to have an overall strong correlation between the two tests ($\tau b = 0.79$, $p < 0.001$). Moreover, separate correlation analyses were conducted for each age group, which demonstrated a significant moderate to strong correlation as displayed in ►**Table 3**.

Discussion

The present study revealed that the response rates for PPT and DPT using vowel /a/ improved with increasing age. The children in group I corresponding to 5 to 5.11 years exhibited a response rate of 45% and 50% for DPT and PPT using vowel, respectively. The response rate for both tests was observed to increase to 65% in group II, which consisted of children aged 6 to 6.11 years. Furthermore, the response rate significantly improved to 100% for both tests among children in group III (aged 7–7.11 years), group IV (aged 8–8.11 years), and group V (aged 9–9.11 years). To our knowledge, these findings have not been previously documented in the literature. Nevertheless, they are in coherence with the results of earlier temporal ordering studies, which consistently reported enhanced scores in children with increasing age.[2,12]

In the present study, no statistically significant differences ($p > 0.05$) were observed in the test results between the two genders. Similar findings had been reported earlier as well where the scores of DPT and PPT were relatable across different genders.[7,30,31] On the other hand, in the study by Balen et al in 2019, it was found that males had significantly higher scores than females.[12] Nevertheless, the authors could not provide a specific explanation for these results and the gender disparities of this nature had not been documented in the literature before their research.

There was a noticeable and consistent increase in scores for both tests across age groups, 5 to 9 years. Numerous studies investigating the development of hearing abilities have consistently demonstrated better performance in older children compared to younger ones.[3,7,28,29] Additionally, these studies have indicated that the maturation of auditory nervous system reaches its completion between the ages of 6 and 12 years.[3] These collective results strongly suggest that temporal ordering develops till adolescence. These observations support the finding that the maturation of auditory nervous system reaches its completion between the ages of 6 and 12 years.[32–35]

Even though the results of PPT and DPT for vowels aligned with earlier research indicating an improvement in scores with age, the scores obtained were lower than those obtained for their tonal counterparts. Humming the verbal sequences demands a relatively more complex phenomenon that needs neuromaturation of the nervous system.[27] In case of PPT, these score differences might have been due to the large

Table 3 Relationship of the scores of the duration pattern test and pitch pattern test across age groups

Age groups	Temporal ordering test	Kendall Tau *b* coefficient		
		τb	p	Interpretation
Group I (5 to 5.11 years)	Duration pattern test	0.82	< 0.001	Strong
	Pitch pattern test			
Group II (6 to 6.11 years)	Duration pattern test	0.77	< 0.001	Strong
	Pitch pattern test			
Group III (7 to 7.11 years)	Duration pattern test	0.50	0.01	Moderate
	Pitch pattern test			
Group IV (8 to 8.11 years)	Duration pattern test	0.48	0.01	Moderate
	Pitch pattern test			
Group V (9 to 9.11 years)	Duration pattern test	0.75	< 0.001	Strong
	Pitch pattern test			

frequency difference of the stimuli used for the tonal version of PPT (i.e., 880 Hz and 1,122 Hz)[10] compared to the PPT based on vowels (220 Hz and 261 Hz). In addition, the difficulty was observed in a majority of the participants in discriminating the verbal sequences in terms of pitch and duration followed by humming them back. This likely stems from the complexity of tasks requiring attention, memory, and the translation of verbal stimuli into humming. The added difficulty in perceiving the patterns of the vowel /a/ based on pitch and duration, ordering the sequences, and labeling them with hum may have contributed to these challenges than tonal stimuli.[12,20] Moreover, the observed variation could be due to the utilization of a microphone for the recording of vowel that did not conform to laboratory standards. This observation suggests that there may be differences in how children respond to vowel and tonal stimuli in terms of hearing development and auditory processing and therefore, should be taken with caution and needs further exploration.

Furthermore, the present study uncovered a substantial relationship between the DPT and PPT using vowel /a/. Despite PPT scores being relatively superior to DPT, a moderate to strong relationship was observed. A comparable pattern was noted in the study by Balen et al, where a strong correlation was identified between the performance on the PPT and DPT among children in the age range of 7 to 11 years.[12] In the study involving patients with central auditory nervous system lesions, a smaller percentage of individuals were found to exhibit impaired performance on PPT compared to DPT, therefore, leading to the hypothesis that these tests engage distinct functional processes.[36] Nonetheless, the observed strong correlation between the two tests in the current study could potentially be attributed to the inherent nature of the temporal ordering task present in both tests, coupled with the inclusion of typically developing, normal-hearing children devoid of any medical history or insults—thus mirroring the conditions detailed in the study by Balen et al. Additionally, Balen et al highlighted a ceiling effect in the PPT when using tone for humming responses,[12] a phenomenon not observed any of the tests using vowel in the current study. This differentiation could potentially be linked to the increased difficulty in executing temporal ordering tasks with vowel sounds and could be attributed to the complexity of these tasks, which demand significant attention, memory, and the ability to translate verbal stimuli into humming.[20,25] Further, it could be due to relatively narrow difference of fundamental frequencies between high and low tones of 41 Hz than that of the one used by Balen et al.[12] However, further investigations are necessary to gain a more comprehensive understanding of this phenomenon.

Conclusion

The present study developed the DPT and PPT using the vowel /a/ to assess temporal ordering skills in typically developing children. Results indicated that both DPT and PPT using the vowel /a/ can evaluate temporal ordering skills across genders and various age groups, showing a consistent increase in scores in children aged from 5 to 9 years. Importantly, both tests did not exhibit a ceiling effect, for both response modes. Nonetheless, limitations such as a narrow age range among participants were noted. Future research should focus on exploring the applicability and effectiveness of PPT with vowels across a wider clinical demographic.

Authors' Contributions

A.K.N.: Contribution: conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; software; roles/writing - original draft; writing - editing; C.S.V.: Contribution: conceptualization; data curation; formal analysis; investigation; methodology; resources; supervision; roles/writing - original draft; writing - review and editing.

Ethical Approval

The study was approved by the research advisory committee and the Institutional Ethics Committee (REF: BVDUMC/IEC/190, dated: August 17, 2022). Informed assent was taken from the children participating in the study.

Conflict of interest

None declared.

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