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# Parents reported language development and scholastic achievement in children with congenital heart diseases versus typically developed

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## Abstract

**Background** Children with congenital heart diseases (CHD) may have developmental delays including delayed language development (DLD) and learning difficulties. The purpose of this study was to observe the effects of CHD on language developmental profile and scholastic achievement (SA) with particular emphasis on prevalence of DLD and SA, potential risks, and need for early intervention.

**Results** This case–control study included 158 children with CHD and 145 healthy children as controls. Participants' ages ranged from 6 months to 15 years. Data were collected by reviewing clinical records and questionnaires covering potential risks, motor and language development, and SA. Potential risks were analyzed using the Fisher test, while language development and SA were compared using Mann–Whitney test. The incidences of parent consanguinity, family history of DLD, and neonatal cyanosis were higher than expected by chance in the CHD group with *p*-values which are < 0.001, 0.044, and < 0.001, respectively. The CHD group revealed more delay in babbling, first word production, two-word sentences, three-word sentences, narration, and SA than control group with significant differences. These comparisons' *p*-values are 0.002, < 0.001, 0.009, 0.029, 0.03, and 0.042 respectively with mean effect size 0.3. The language development profile in cyanotic HD showed more delay than acyanotic HD with significant differences.

**Conclusions** The DLD and affected SA were more prevalent in children with CHD. The risk for DLD in CHD children was multifactorial; however, the main predisposing factor was chronic hypoxia that starts in the intrauterine life in CHD. Neonates with CHD require early intervention through oxygen therapy before surgery. Early family counseling and language therapy are recommended to improve quality of life through achieving better communicative ability and academic skills. Further studies which concerned the effect of maternal oxygenation on prognosis of fetuses with CHD may be required. Also, duplication of the study including formal testing is recommended.

**Keywords** Congenital heart diseases, Language development profile, Delayed language development, Scholastic achievement, Hypoxia

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## Background

Congenital heart disease (CHD) is one of the most common congenital diseases in children [1]. Children with CHD may present with severe developmental delays and neuropsychological deficits, which could be more severe in cyanotic heart disease [2–4]. One neuropsychological deficit is delayed language development (DLD). This DLD appears in different forms: phonological, expressive, or receptive language [4]. Some researchers have reported that language development in children with CHD may not proceed as in healthy children and may place them at risk for learning difficulties in school [4]. However, some children with CHD who have language problems may develop language after surgery [1, 2, 5].

Children with CHD in the second year of life have lower language performance in both receptive and expressive domains compared to normal peers. Therefore, language development in this population requires close follow-up to see whether such language delays progress into significant troubles with growing environmental demands [4]. In general, children with CHD are at risk of DLD [4–7] and reduced scholastic achievement [8, 9]. Also, Down's syndrome comorbid with CHD revealed lower scores in language abilities compared to Down's syndrome without CHD [10]. Developmental delay in young children with CHD is common and dynamic. So, prevalence of developmental delay in CHD changes over time because of different risk exposures [11]. Surveillance of both language and academic skills in children with CHD is important to detect the developmental profiles and risk factors. Such studies are lacking in the literature. Therefore, the purpose of the current study is to focus on and estimate the prevalence of DLD, affected scholastic achievement, and any additional potential risk factor in children with CHD. This will help proper decision-making as regard prevention and treatment of the developmental delay in CHD children.

## Methods

This case–control study was carried out to evaluate language development profile and scholastic achievement ability in children with CHD compared to healthy children. This is to observe and assess the potential risks related to the DLD in CHD children if any. The official local Institutional Review Board (IRB) approved this study. Written informed consents were obtained from all participants' parents in this study. Our study included 158 children with CHD who received their treatment (CHD group). The inclusion criterion is children with CHD not more than ninth grade school or 15 years old. The exclusion criteria are CHD associated with any known cause of DLD like syndromic CHD (e.g., Down syndrome), hearing impairment, neurological or psychiatric disorders, and intellectual disability due to other obvious cause which is not related to the CHD. The main follow-up visits were in pediatric cardiac clinic, and finally, the patients were referred to the phoniatric clinic where history taking and language evaluation were done. The data were collected by reviewing clinical records from pediatric cardiac clinic and phoniatrics clinic on the computer software Medica CloudCare version 2. In addition, data were collected by questionnaires given to the parents of children with CHD presented in the period from Sept 2021 to November 2023. Questionnaire forms were given to every participant's family to fill in, which takes approximately 5 min. The form contains 29 questions that covered potential risk factors, developmental history, and treatment history. The yes/no questions ask for parent consanguinity, similar condition of CHD or DLD in the family, fever with pregnancy, preeclampsia, anemia with pregnancy, diabetes mellitus with pregnancy, delayed first cry after birth, cyanosis, jaundice, incubation, neonatal fever, low birth weight, hereditary disease related to CHD, need for other surgery, and history of language therapy. For jaundice, a detailed answer collected is as follows: no jaundice, yes little < 12 mg/dl, yes 12–18 mg/dl, yes more than 18 mg/dl, and yes needed blood transfusion. Motoric development of children was assessed by age the child can walk unsupported and control toilet. The walking ability was scored from 1 to 3 where 3 represents typical development and 1 represents severe delay. Walking scores are as follows: score 3 when walking started from 9 to 11 months, 2 when walking started from 12 to 14 months, and 1 when walking started after 14 months. The toilet control was scored from 1 to 4 where 4 represents typical development and 1 represents severe delay. Toilet control scores are as follows: score 4 means toilet control by 2 years, 3 means toilet control occurred from 2 to 2.5 years, 2 when toilet control occurred between 2.5 and 3 years, and 1 when toilet control occurred after 3 years. The current receptive language (RL) ability in the CHD group was assessed by asking children to identify items of semantic groups through pointing. Children who identified more than 75% of semantic items were considered with good RL, while children identified 25–50% of semantic items were considered with fair RL. Finally, children identified less than 25% of semantic items were considered with poor RL. Expressive language ability is the explicit form of language for the family. So, expressive language ability was scored from 4 to 1 where score 4 represents the typically developed language, while score 1 represents the most delayed language development. The ages of norms regarding expressive language abilities were considered in the questionnaire according to the Arabic language test developed by Kotby et al. [12] and the Preschool

Language Scale 4 standardized and translated by Abu Haseeba et al. [13].

| | |
|---|---|
| Babbling | |
| Score 4: Started from 4 to 6 months | Score 3: From 7 to 9 months |
| Score 2: From 10 to 12 months | Score 1: More than 12 months |
| First word production | |
| Score 4: Started from 10 to 14 months | Score 3: From 15 to 18 months |
| Score 2: From 19 to 24 months | Score 1: More than 24 months |
| The two-word sentence production | |
| Score 4: Started from 20 to 24 months | Score 3: From 24 to 30 months |
| Score 2: From 31 to 36 months | Score 1: More than 36 months |
| The three-word sentence production | |
| Score 4: Started from 2 to 2.5 years | Score 3: From 2.5 to 3 years |
| Score 2: From 3 to 3.5 years | Score 1: More than 3.5 years |
| Narration | |
| Score 4: Started from 3 to 4 years | Score 3: From 4 to 5 years |
| Score 2: From 5 to 6 years | Score 1: More than 6 years |

#### Scholastic achievement (SA)

This ability was scored according to the level of SA in school based on the mean score of the last two semesters. The SA was scored from 4 down to 1, where score 4 represents good and score 1 represents poor achievement. Children younger than school age were not scored for SA (not applicable). Scoring system for SA was considered as follows:

| | |
|---|---|
| Score 4: Good (> 75%) | Score 3: Average (65–74%) |
| Score 2: Below average (55–64%) | Score 1: Poor (< 55%) |

The same information was collected from volunteers of healthy children who have no CHD as the control group ($n = 145$). Children of the control group were recruited from the same population and geographic distribution whose ages and sexes were matched with the CHD group. Parents of volunteers have no complaints regarding language ability. Comparisons of language development and SA were performed between the two groups. In addition, comparisons of the same parameters will be conducted between cyanotic and acyanotic CHD within the CHD group.

#### Statistics

All comparisons were carried out using nonparametric unpaired *t*-test (Mann–Whitney test) with two-tailed *p*-values because our data are in the form of scores which is discrete noncontinuous data. The Fisher test was applied for potential risk factors in the two groups because it assesses the retrospective relative risks. All statistics were conducted using GraphPad Prism Software Version 8. The power of study was calculated by the given means of scores, standard deviations, and sample size of both groups.

## Results

The descriptive statistics of the participant's personal information revealed that the CHD group included 89 females and 69 males, and their ages ranged from 2 to 15 years with median 6.75, and the average ± SD is 7.15 ± 3.3. On the other hand, the control group included 80 females and 65 males, and their ages ranged from 2 to 14 years with median 6, and average ± SD is 6.2 ± 3.2. There were no significant differences in the distributions of age or sex in both groups. Statistical analysis of the relative risks showed that prevalence of parent consanguinity, family history of DLD, and neonatal cyanosis were higher in the CHD group than control group with discrepancies more than expected by chance (Table 1). Neonatal cyanosis included cyanosis at birth and the repeated and chronic cyanosis in the neonatal period. Neonatal cyanosis was prevalent in the CHD group with highly significant discrepancy followed by parent consanguinity and family history of DLD. Other relative risks were not shown significant discrepancy between groups. The prevalence of jaundice was high in the control group; however, it was mild (less than 12 mg/dl). In the CHD group, mild jaundice less than 12 mg/dl was found in 25 cases (16%), moderate jaundice from 12 to 18 mg/dl was found in 2 cases (1.3%), and severe jaundice which needed blood transfusion was found in 1 case (0.6%). The prevalence of jaundice did not show significant discrepancy between the two groups.

The motor development including scores of walking and toilet control did not reveal any significant differences between the two groups. The mean score of walking in CHD group was 1.72 ± 0.7 compared to 1.79 ± 0.6 in the control group. Also, the mean score of toilet control was 2.34 ± 1.1 and 2.46 ± 0.67 in the CHD and control groups respectively. The current receptive language (RL) ability was assessed for children with DLD in CHD group. There were 83 children with DLD in the CHD group (52.5%). Among them, 26 children (16.4%) have good RL ability, 25 children (15.8%) have fair RL ability, and 32 children (20.2%) have poor RL ability.

Expressive language development and academic achievement were compared between CHD group ($n = 158$) and control group ($n = 145$) using the unpaired nonparametric Mann–Whitney test with two-tailed *p*-values. These comparisons revealed that CHD group has lower scores than control group with significant differences as shown in Table 2.

1. *Babbling*

**Table 1** Relative risks for DLD in both groups

| Potential risk | CHD group Number (%) | Control group Number (%) | Fisher exact test | | |
|---|---|---|---|---|---|
| | | | *p*-value | Odd ratio | Confidence interval 95% |
| **Parent consanguinity** | 102 (65%) | 35 (24.13%) | **<0.001** | 5.7 | 3.4 to 9.2 |
| **Family history of DLD** | 68 (43%) | 46 (31.7%) | **0.044** | 1.6 | 1 to 2.6 |
| **Family history of CHD** | 22 (14%) | – | – | – | – |
| **Prenatal fever** | 9 (5.7%) | 8 (5.5%) | > 0.9 | 1 | 0.4 to 2.7 |
| **DM with pregnancy** | 5 (3.2) | 12 (8.27%) | 0.078 | 0.36 | 0.138 to 1 |
| **Anemia with pregnancy** | 12 (7.6%) | 7 (4.8%) | 0.35 | 1.6 | 0.64 to 4.16 |
| **Preeclampsia** | 3 (1.9%) | 5 (3.44%) | | | |
| **Cyanosis** | 46 (29%) | 5 (3.44%) | **<0.001** | 11.5 | 4.44 to 27.43 |
| **Incubation** | 5 (3.2%) | 8 (5.5%) | 0.39 | 0.55 | 2 to 1.8 |
| **Low birth weight** | 6 (3.8%) | 6 (4.13%) | > 0.9 | 0.9 | 0.28 to 2.9 |
| **Jaundice** | 28 (17.7%) | 40 (27.6%) | 0.053 | 0.56 | 0.33 to 0.96 |
| **Neonatal fever** | 6 (3.8%) | 4 (2.75%) | 0.7 | 1.4 | 0.36 to 4.4 |
| **Total** | **158** | **145** | | | |

Shows results of the Fisher exact test for the possible predisposing factors of delayed language development

Significant results are underlined and in bold font. *CHD*, congenital heart diseases; *DLD*, delayed language development; *DM*, diabetes mellitus

**Table 2** Comparison of language development and scholastic achievement profiles

| Language stage | Score group | 1 | 2 | 3 | 4 | Total no | Mean ± SD | *p*-values | Effect size |
|---|---|---|---|---|---|---|---|---|---|
| **Babbling** | CHD | 2 | 18 | 50 | 88 | 158 | 3.4 ± 0.74 | 0.002 | 0.28 |
| | Controls | 2 | 12 | 22 | 109 | 145 | 3.6 ± 0.72 | | |
| **First word** | CHD | 1 | 19 | 45 | 93 | 158 | 3.45 ± 0.7 | < 0.001 | 0.47 |
| | Controls | 0 | 1 | 35 | 109 | 145 | 3.74 ± 0.45 | | |
| **Two-word sentence** | CHD | 3 | 14 | 61 | 75 | 153 | 3.36 ± 0.7 | 0.009 | 0.18 |
| | Controls | 8 | 4 | 32 | 90 | 134 | 3.5 ± 0.8 | | |
| **Three-word sentence** | CHD | 1 | 17 | 65 | 66 | 149 | 3.3 ± 0.7 | 0.029 | 0.37 |
| | Controls | 0 | 2 | 55 | 67 | 124 | 3.5 ± 0.53 | | |
| **Narration** | CHD | 0 | 8 | 57 | 68 | 133 | 3.45 ± 0.6 | 0.03 | 0.26 |
| | Controls | 0 | 4 | 33 | 69 | 106 | 3.6 ± 0.56 | | |
| **Scholastic achievement** | CHD | 3 | 16 | 26 | 46 | 91 | 3.26 ± 0.86 | 0.042 | 0.4 |
| | Controls | 0 | 2 | 33 | 49 | 84 | 3.56 ± 0.54 | | |

This table shows comparisons of language development and scholastic achievement (SA) scores between congenital heart diseases (CHD) and control groups. Distribution of children number in both groups was shown for each score. Note that the CHD group has lower language and SA scores than controls with significant differences

There were 5, 9, and 25 children with CHD who were not scored for two-word and three-word sentences and narration respectively because their expressive language ability did not reach the assessed language level. Also, 67 children with CHD were not scored for scholastic achievement because they were young for school. Similarly, there were 11, 21, 39, and 61 control children who were not scored for two-word and three-word sentences, narration, and scholastic achievement respectively

There are 70 children (44.3%) showing delayed babbling in the CHD group compared to 36 children (24.8%) in the control group. The average babbling score in the CHD group is lower than that in control group with significant difference, $p = 0.002$ (Fig. 1a).

2. *First word production*

There are 65 children (41%) in the CHD group showing delayed first word production as they produced their first word at age of 15 months or more compared to 36 children (24.8%) in control group. The average score of first word production in the CHD

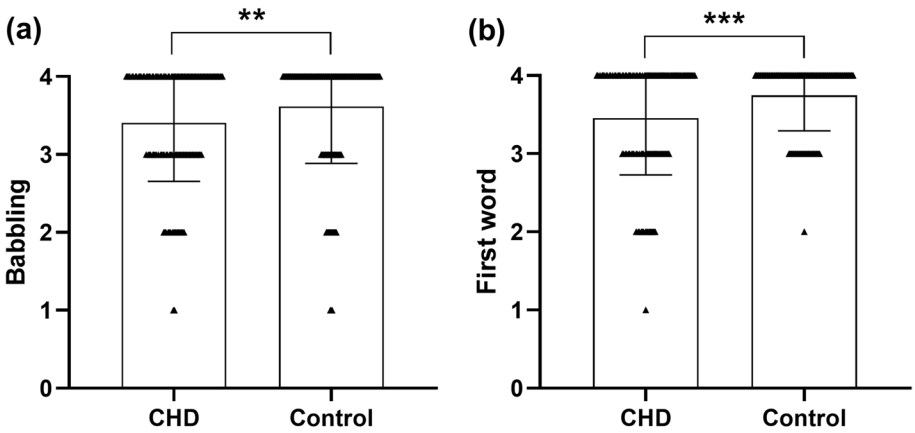


**Fig. 1** This figure shows comparison result of language profile between CHD and control groups with Mann–Whitney test. Note the CHD group has lower score of babbling than control group with significant difference (**a**). Also, the CHD group has a lower score of first word production than control group with significant difference (**b**). CHD, congenital heart disease; $^{**}p < 0.01$; $^{***}p < 0.001$

groups is lower than that in the control group with significant difference, $p < 0.001$ (Fig. 1b).

3. *The two-word sentence production*
   There are 5 children in the CHD group, and 11 children in the control group were not scored for the two-word sentence production because their ages ranged from 24 to 26 months. Moreover, there are 78 children (50.9%) in the CHD group who showed delayed uttering two-word sentences compared to 44 children (32.8%) in the control group showed such delay. The average score of the two-word sentence production in the CHD group is lower than that in the control group with significant difference, $p = 0.009$ (Fig. 2a).
4. *The three-word sentence production*
   There are 9 children in the CHD group, and 21 children in the control group were not assessed for three-word sentences production because their ages ranged from 27 to 30 months. There are 83 children (55.7%) in the CHD group revealing delay in producing three-word sentences compared to 57 children (45.9%) in the control group. The average score of the three-word sentence production in the CHD group is lower than that in the control group with significant difference, $p = 0.029$ (Fig. 2b).
5. *Narration*
   There are 25 children in the CHD group, and 39 children in the control group were not assessed for narration because their ages are less than 3 years. There are 65 children (48.8%) in the CHD group showing

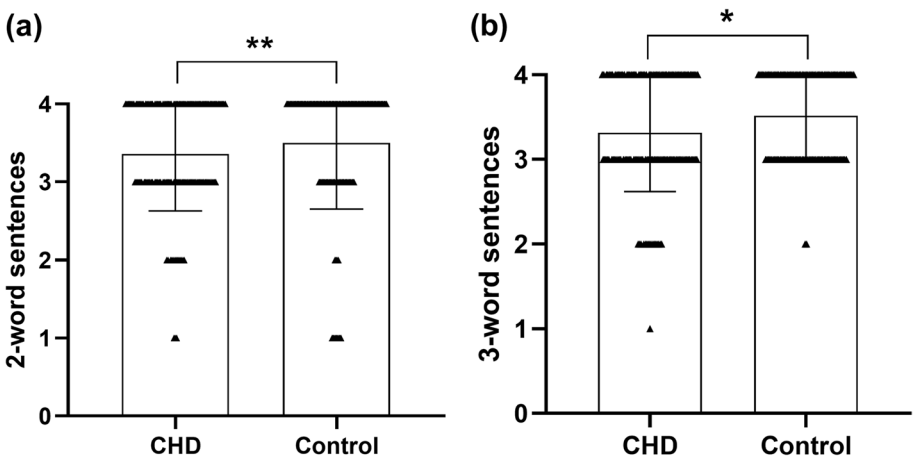


**Fig. 2** This figure shows comparison result of language profile between CHD and control groups with Mann–Whitney test. Note CHD group has lower score of two-word sentences than control group with significant difference (**a**). Also, the CHD group has a lower score of three-word sentence than control group with significant difference (**b**). CHD, congenital heart disease; $^{*}p < 0.5$; $^{**}p < 0.01$

delayed narration compared to 37 children (34.9%) in the control group. The average score of narration in the CHD group is lower than that in the control group with significant difference, $p=0.03$ (Fig. 3a).

6. *Scholastic achievement (SA)*
   Only 92 children in the CHD group and 84 children in the control groups have been scored for SA, and the scoring distribution was shown in Table 1. This is because 66 children in the CHD and 61 children in the control groups were younger than school age. There are 45 children (48.9%) of scored children in the CHD group, and 35 children (41.6%) of scored children in the control group have affected SA. The average score of SA in the CHD group is lower than that in the control group with significant difference, $p=0.042$ (Fig. 3b).

Distribution of the children with CHD as regard their diagnosis was shown in Table 3. In addition, language development profile and academic achievement were compared between cyanotic and acyanotic CHD with mean effect size 1.5. It was found that children with cyanotic CHD have more language delay and more affected scholastic achievement than children with acyanotic CHD with significant differences ($p<0.001$ and $p=0.004$ respectively) as shown in Table 4.

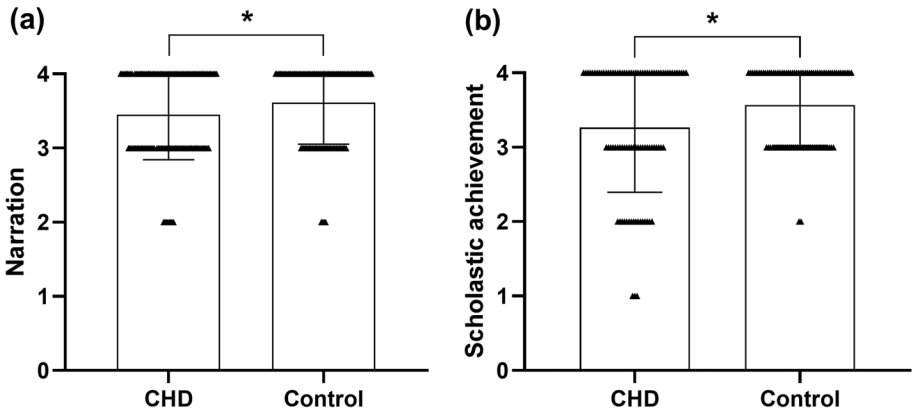


**Fig. 3** This figure shows comparison result of language profile and scholastic achievement between CHD and control groups with Mann–Whitney test. Note CHD group has lower score of narration than control group with significant difference (**a**). Also, the CHD group has a lower score of scholastic achievement than control group with significant difference (**b**). CHD, congenital heart disease; *$p<0.05$

**Table 3** Distribution of diagnoses either cyanotic or acyanotic CHD

| Cyanotic CHD | Number of subjects | Acyanotic CHD | Number of subjects |
|---|---|---|---|
| Fallot's tetralogy | 7 | VSD | 77 |
| Transposition of the great arteries | 7 | Secundum ASD | 25 |
| Left ventricular hypoplasia | 3 | Pulmonary stenosis | 9 |
| Tricuspid atresia | 2 | Coarctation of the aorta | 6 |
| Truncus arteriosus | 1 | Primum ASD | 6 |
| Total anomalous pulmonary venous return | 1 | Bicuspid aortic valve | 3 |
| | | Mitral valve stenosis | 2 |
| | | Aortic stenosis | 1 |
| | | Subaortic membrane | 1 |
| | | Mitral valve prolapse | 1 |
| | | Double outlet right ventricle | 1 |
| | | Atrioventricular septal defect | 1 |
| | | Ebstein anomaly | 1 |
| Subtotal no. of diagnoses | 21 (13.5%) | | 135 (86.5%) |
| **Total no. of subjects** | **151** | | |

This table shows distribution of children with CHD as regard their diagnosis. Note the number of diagnoses is more than the number of subjects because VSD diagnosis was found comorbid with other cardiac anomalies. *CHD*, congenital heart disease; *VSD*, ventricular septal defect; *ASD*, atrial septal defect

**Table 4** Comparison of cyanotic and acyanotic CHD

| Item | Cyanotic HD Mean ± SD | Acyanotic HD Mean ± SD | *p*-values | Effect size |
|---|---|---|---|---|
| Babbling | 2.2 ± 0.6 | 3.6 ± 0.57 | $p < 0.001$ | 2.4 |
| First word production | 2.24 ± 0.54 | 3.64 ± 0.5 | $p < 0.001$ | 2.5 |
| Two-word sentences | 2.57 ± 0.6 | 3.49 ± 0.66 | $p < 0.001$ | 1.4 |
| Three-word sentences | 2.76 ± 0.44 | 3.4 ± 0.68 | $p < 0.001$ | 1 |
| Narration | 2.95 ± 0.38 | 3.5 ± 0.58 | $p < 0.001$ | 1 |
| Scholastic achievement | 2.86 ± 0.36 | 3.38 ± 0.84 | $p = 0.004$ | 0.65 |

This table shows comparisons of language development and scholastic achievement between children with cyanotic and children with acyanotic congenital heart disease (CHD). Note that children with cyanotic CHD have lower language and SA scores than children with acyanotic CHD with highly significant differences

Language development and scholastic achievement according to age groups revealed significant differences between the two groups which were in babbling, first word, and two-word sentence production in children younger than 5 years. The difference shifted to the three-word sentences in children aged 5–10 years. Finally, the main differences were in narration and academic skills in children older than 10 years (Table 5).

### Statistical analysis

The Mann–Whitney test was performed for comparing language and SA scores between CHD and control groups. The resulting *p*-values were two-tailed and approximate. The Fisher test was applied to examine the potential risk factors with two-sided *p*-values and 95% confidence intervals. The power and sample size were calculated using G*Power software. The mean power of the study is 0.99, and the mean effect size is 0.74. Total

**Table 5** Comparison of language development and scholastic achievement according to age groups

| Age group | Assessment | Number | | Mean ± SD | | *p*-value | Effect size |
|---|---|---|---|---|---|---|---|
| | | CHD | Cont | CHD | Controls | | |
| **< 5 years** | **Babbling** | 55 | 67 | 3.4 ± 0.76 | 3.75 ± 0.6 | 0.003** | 0.68 |
| | **First word** | 55 | 67 | 3.37 ± 0.78 | 3.78 ± 0.4 | 0.001*** | 0.68 |
| | **Two-word sent** | 51 | 58 | 3.3 ± 0.75 | 3.5 ± 0.78 | 0.04* | 0.7 |
| | **Three-word sent** | 46 | 48 | 3.4 ± 0.78 | 3.5 ± 0.5 | 0.3 ns | 0.77 |
| | **Narration** | 34 | 40 | 3.6 ± 0.6 | 3.7 ± 0.47 | 0.5 ns | 0.87 |
| | **SA** | – | – | NA | NA | NA | NA |
| **5–10 years** | **Babbling** | 78 | 62 | 3.4 ± 0.74 | 3.5 ± 0.75 | 0.1 ns | 0.63 |
| | **First word** | 78 | 62 | 3.5 ± 0.7 | 3.7 ± 0.5 | 0.1 ns | 0.63 |
| | **Two-word sent** | 77 | 60 | 3.4 ± 0.72 | 3.4 ± 0.9 | 0.4 ns | 0.64 |
| | **Three-word sent** | 78 | 60 | 3.3 ± 0.67 | 3.7 ± 0.47 | 0.007** | 0.63 |
| | **Narration** | 74 | 50 | 3.47 ± 0.6 | 3.6 ± 0.54 | 0.3 ns | 0.68 |
| | **SA** | 66 | 51 | 3.36 ± 0.8 | 3.6 ± 0.53 | 0.1 ns | 0.7 |
| **> 10 years** | **Babbling** | 25 | 16 | 3.24 ± 0.72 | 3.75 ± 0.44 | 0.02* | 1.2 |
| | **First word** | 25 | 16 | 3.4 ± 0.7 | 3.68 ± 0.47 | 0.2 ns | 1.2 |
| | **Two-word sent** | 25 | 16 | 3 ± 0.65 | 3.62 ± 0.5 | 0.012* | 1.2 |
| | **Three-word sent** | 25 | 16 | 3.2 ± 0.57 | 3.37 ± 0.6 | 0.3 ns | 1.2 |
| | **Narration** | 25 | 16 | 3.2 ± 0.48 | 3.7 ± 0.47 | 0.003** | 1.2 |
| | **SA** | 25 | 16 | 3 ± 1 | 3.68 ± 0.47 | 0.04* | 1.2 |

This table shows comparisons of language development and scholastic achievement according to age groups. Note: There were 5, 9, and 25 children with CHD who were not scored for two-word and three-word sentences and narration respectively because their expressive language ability did not reach the assessed language level. Also, 67 children with CHD were not scored for scholastic achievement because they were young for school. Similarly, there were 11, 21, 39, and 61 control children who were not scored for two-word and three-word sentences, narration, and scholastic achievement respectively. Most of these children were in age group < 5 years and few in age group 5–10 years as shown in the table. *CHD*, congenital heart disease; *Cont*, controls; *SA*, scholastic achievement; *NA*, not applicable; *ns*, not significant, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

sample size was calculated as 144. So, the sample size of the current study is appropriate.

## Discussion

In the current study, we found the mean percentage of the CHD children suffering from DLD is 48% compared to 32.6% in control children with significant differences in the five levels of expressive language abilities. Also, these differences decreased over time denoting improvement of expressive language in the CHD group. Despite the parents of the control group did not complain of any language delay in their children, however and surprisingly, we found high prevalence of DLD in both groups. There are 52.4% of the control, and 55.7% of the CHD groups have delayed uttering three-word sentences. This can be explained by poor family compliance and lack of parents' ability to detect language delay in their children, which related to poor knowledge of the normal language development. This finding is consistent with previous research in the same country [14].

The main cause of DLD found in CHD group is the congenital heart disease itself, which resulted in chronic hypoxemia and possible cognitive impairment. Cyanosis at birth or in the neonatal period is a significant predisposing factor for DLD in the CHD group. Children born with cyanotic CHD usually have repeated cyanosis in neonatal period, which has adverse effects on brain and cognitive development causing slow acquisition of language with subsequent DLD. The chronic hypoxia in cyanotic CHD can interfere with typical brain development [15]. Chronic hypoxic environment can induce extensive cognitive impairment with decreased gray matter density in multiple brain regions [16]. In previous study included 25 children with cardiac diseases, 56% of children had DLD, 48% due to below average mentality and 8% due to intellectual disability. Children with chronic cardiac diseases had lower scores in language ability and intelligence quotient indicating impaired neurocognitive function [1]. Term infants with hypoplastic left heart syndrome and transposition of the great arteries have brains that are smaller and structurally less mature than expected. This delay in brain development may foster susceptibility to periventricular leukomalacia in the preoperative, intraoperative, and postoperative periods [3]. Neonates with hypoplastic left heart syndrome have significant hemodynamic threats to cerebral perfusion and are at risk of reduced neurodevelopmental performance [17]. Also, it has been found that children with tetralogy of Fallot have lower intelligence, difficulties with language tasks, and mild motor deficits. In addition, parents of the children with tetralogy of Fallot indicated attention problems and lower school competencies compared to healthy control subjects [18]. However, children who underwent early surgery for transposition of great arteries ($n=7$) in the current study showed noticeable improvement in attention, cognition, and expressive language abilities few months after surgery as reported by their parent. This is consistent with previous studies [1, 2, 5]. Treatments of our children were urgent surgery in 43 children (27.2%), delayed surgery in 12 children (7.6%), and follow-up in 103 children (65%). There were seven children (4.4%) required and underwent second surgery.

Also, the parent consanguinity and family history of DLD have been found associated with DLD in both groups of the current study. These findings are consistent with previous study carried out on the same community. In their study, speech delay was found in 45.5% of children. In that study, the family history of developmental communication disorder was found significantly associated with the speech delay [19]. Parent consanguinity and similar family history of DLD may be potential risks for developmental language delay or SLI [20]. Also, the risk for congenital heart disease is increased in consanguineous marriage, principally at first cousin level [21]. Such kind of endogamy is very common in our community and in the population of study. So, parent consanguinity is a common risk factor for both developmental language delay and CHD. In addition, there are 49.4% of the assessed children with CHD, and 41.6% of the assessed children in the control group have affected scholastic achievement in at least one ability (either reading, writing, calculation, or abstract thinking and problem-solving). The affected scholastic achievement in children younger than 10 years was mainly in reading, writing, and calculation abilities. However, children with affected scholastic achievement older than 10 years were mainly suffering from affected abstract thinking and problem-solving. The CHD and associated chronic hypoxia could be the responsible factor for DLD and affected SA in the CHD group. DLD has been found to affect both groups in the studied population with more impact on CHD group. Also, we found the prevalence of affected SA is high in both groups but higher in CHD group. This high prevalence is consistent with previous study carried out in the same population [22]. Moreover, there is a proven relationship between developmental language delay and literacy problem [23]. In the current study, at least part of the DLD may be related to developmental language disorder. Children who are suspected to have developmental language disorder represented 14.5% in the CHD group ($n=23$) and 12.4% in the control group ($n=18$). These children have good cognitive ability and family history of at least one similar case of DLD. Cognitive ability was judged roughly by parents who reported that their children know everything and can respond well to commands, but they are unable to speak clearly.

Among the 83 children (52.5%) with DLD in CHD group, there were 26 children (16.4%) who had good RL ability and were suspected to have developmental language disorder. Also, there were 25 children (15.8%) with fair RL ability and may be related at least in part to environmental deprivation. The remaining 32 children (20.2%) had poor RL ability and most probably related to CHD. On the other hand, 57 children with DLD in the control group (39.3%) did not undergo assessment for RL. However, there are 27 children (18.6%) of control children who know everything with good response to commands according to telephone call to parents. These children were suspected to have developmental language disorder, while the remaining children could be slow starters or related to environmental deprivation. However, these are just preliminary results, and confirmation of these diagnoses required additional formal tests, especially for IQ.

Repeated hospitalization and long hospital stay of children with CHD may be other risk factors for DLD. In hospitalization, deprivation of language-stimulating environment and reduced discovery of the surrounding environment may lead to DLD. In addition, the long indoor stay with environmental deprivation and exposure of children to screens for extended periods during COVID-19 adversely affected language development in younger children especially in the critical period of language acquisition, which is the first 3 years of life. Fifty-four children with CHD (34%) and 70 control children (48.3%) had their ages ≤ 5 years during data collection. This means that their ages were ≤ 3 years during COVID-19, and they spent about 2 years of this critical period in the pandemic with its precaution and environmental deprivation consequences. Similarly, the remote school attendance for 2-year duration during the pandemic with no direct participation in class theoretically might adversely affect scholastic achievement in both groups.

Moreover, there are risk factors for perioperative brain injury that could be responsible for cognitive impairment and DLD in CHD as reported in previous study. These risk factors included immature central nervous system development, chronic hypoxia-related neuroinflammatory reactions, hyperviscosity and coagulation dysfunction, and changes in the levels of neurochemicals in the central nervous system, oxidative stress due to high level of oxygenation, and cerebrovascular microembolism [24]. Furthermore, feeding difficulty, poor growth, medical comorbidities, and more complex treatments in CHD are other risk factors for DLD. Therefore, the cause of DLD in CHD is multifactorial including mainly chronic brain hypoxia and environmental deprivation. Family counseling to work on language stimulation early in life with extensive language therapy after 2 years of age can improve language ability and prevent learning problems.

Oxygen therapy by administration of supplemental oxygen in the blood was started in the symptomatic CHD children in the current study to compensate for reduced oxygen levels in their blood. The timing of oxygen therapy depends on the severity of cyanosis and the patient's stability. Oxygen therapy is typically started in symptomatic patients with significant cyanosis or those with a history of spells [25]. In neonates or infants with cyanotic heart diseases, oxygen therapy may be started immediately after birth or during the neonatal period. Regular monitoring of oxygen saturation levels is essential to assess the effectiveness of oxygen therapy and to adjust the treatment as needed [26]. Oxygen therapy should be continued until the underlying cause of cyanosis is treated and the patient's oxygen saturation level has normalized [27]. Therefore, urgent treatment of cyanotic CHD and even some acyanotic HD like large VSD is critical for normal or nearly normal brain development. The uncorrected VSD may lead to pulmonary hypertension with greater chance of blood flowing from right to left ventricles causing hypoxemia or even cyanosis.

Although children with cyanotic CHD received early oxygen therapy, children with CHD still have higher prevalence of DLD and affected scholastic achievement than controls. This can be explained by the intrauterine hypoxemia of the fetus with cyanotic CHD that may adversely affect the brain development. Also, early oxygen therapy after birth cannot completely prevent cyanosis or hypoxemia because of the time taken to the hospital.

In summary, the language development profile showed more delay in children with CHD compared to controls with significant differences. Moreover, children with cyanotic CHD revealed more delay in language development and scholastic achievement compared to children with acyanotic CHD. A direct link between reduced cerebral oxygenation and impaired brain growth in fetuses with CHD was proven and may raise the possibility that in utero brain development and later prognosis could be improved with maternal oxygen therapy [28–30]. Adequate cerebral perfusion with good oxygenation is mandatory for brain development. The presence of chronic hypoxia during the first 3 years of life can adversely affect brain development, cognitive ability, and language acquisition. Every study has its own drawbacks. The limitation of the current study is being devoid of objective data. Duplication of the study including formal testing for IQ, language ability, and literacy is highly recommended. Also, delineating different types of language disorders in CHD is required including assessment of memory and

attention. Finally, radiological brain finding of children with CHD may need further studies.

## Conclusion

Children born with congenital heart diseases have a higher prevalence of delayed language development and affected scholastic achievement compared to their peers. Chronic hypoxia is the main cause of the language delay and affected scholastic achievement. Other causes in our patients may be related to environmental deprivation and developmental language disorder. Oxygen therapy decreased attacks of hypoxemia and cyanosis in the neonatal period. However, intrauterine hypoxemia in fetuses with cyanotic congenital heart diseases is still a potential risk factor. Therefore, maternal oxygenation may need further research to confirm its impact on brain development, motoric and linguistic developments, and scholastic achievement. An important nonsurgical intervention is family counseling to enhance and improve language-stimulating environment in the first year and intensive language therapy in the second year of life. This may prevent developmental delays including delayed language development and possible learning problems.

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**Authors' contributions**
All authors legitimately claim authorship. All authors made a substantial contribution to the concept, design of the work, and acquisition of data. The corresponding authors MMH and HIE made analysis and interpretation of data. In addition, authors MMH and IA drafted the article. All authors revised the manuscript critically for important intellectual content and approved the version to be published. All authors participated sufficiently in the work.

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**Availability of data and materials**
The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate**
The protocol of this study was reviewed and approved by the Institutional Review Board (IRB), General Directorate of Health Affairs in Madinah MOH, Saudi Arabia. The number of approval is H-03-M-084. Written informed consents were obtained from all participants' parents in this study.

**Consent for publication**
Written informed consents for publication were obtained from all parents.

**Competing interests**
The authors declare that they have no competing interests.

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