Gross Motor Development of Children with Congenital Heart Disease Receiving Early Systematic Surveillance and Individualized Intervention: Brief Report

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Abstract

Objective: In this pilot study, we described the gross motor development of infants aged 4 to 24 months with congenital heart disease (CHD) and assessed through a systematic developmental screening programme, with individualised motor interventions. *Methods*: Thirty infants who had cardiac repair underwent gross motor evaluations using the AIMS at 4 months, and the Bayley-III at 12 and 24 months. *Results*: Based on AIMS, 80% of 4-month-old infants had a delay in gross motor development and required physical therapy. Gross motor abilities significantly improved by 24 months. Infants who benefited from regular physiotherapy tended to show better improvement in motor scores. *Conclusion*: Our study highlights the importance of early motor screening in infants with CHD and suggests a potential benefit of early physical therapy in those at-risk. Further research is needed to assess the effectiveness of systematic developmental screening and individualized intervention programmes at identifying at risk patients, and their impact on developmental outcomes.

Keywords: congenital heart disease; gross motor development; early intervention; Alberta Infant Motor Scales (AIMS); Bayley Scales of Infant and Toddler Development; Third edition (Bayley-III)

Abbreviations

CHD, Congenital heart disease
AIMS, Alberta Infant Motor Scales
Bayley-III, Bayley Scales of Infant and Toddler Development, Third edition
Bayley-III/GM, gross motor scale of the Bayley Scales of Infant and Toddler Development, Third edition

 doi:10.20944/preprints201908.0248.v1

1. Introduction

Children with congenital heart disease (CHD) requiring early cardiac surgery experience a broad spectrum of neurodevelopmental disorders characterized by a combination of mild to moderate motor, cognitive, and language impairments.[1–10] During infancy, gross motor delays typically appear as the primary manifestations of altered neurodevelopment.[2,4,5,9,11] Longitudinal studies investigating motor development in children with CHD revealed a delay in the acquisition of gross motor skills as early as the age of 2 months.[4,5,9,11] In most of these studies, gross motor development was persistently delayed up to the age of 2 years.[5,9,11] At an older age, 39% and 42% of 5-year-old and school-aged children with CHD, respectively, were shown to experience persistent gross motor deficits.[12,13] In contrast, some studies revealed an improvement in motor development during infancy.[5,9] In particular, Mussatto and colleagues reported better motor scores in older CHD children without genetic syndrome, resulting in motor performances similar to those of typically developing infants at the age of 12 months and older.[4] In their study, 74% of children received early intervention services from the US regional early intervention programmes or private services, which raised the possibility of a potential benefit of early intervention on motor development.

In an effort to support neurodevelopment in children with CHD and based on the guideline statement of the American Heart Association and the American Academy of Pediatrics,[1] we established in 2013 an interdisciplinary neurocardiac clinic. We provide early and structured developmental screening including standardized motor assessments at the ages of 4, 12, and 24 months, and older, as well as early individualised intervention sessions to children combined with a psychoeducational support for the parents, tailored to their individual needs.

In a case study, we previously reported significant motor improvement after early intervention in one of our patients with CHD.[14] However, research is still needed to document the motor development of cohorts of infants enrolled in such structured surveillance programmes and to esti-

 doi:10.20944/preprints201908.0248.v1

mate the effects of early physical therapy when provided. Therefore, this pilot study describes the developmental trajectory of gross motor skills in infants with CHD aged between 4 and 24 months enrolled in an early and systematic developmental screening programme.

2. Method

2.1. Participants

All infants with CHD who were referred at birth to the *Clinique d'Investigation Neurocardiaque* (CINC) of the Sainte-Justine University Hospital Centre, in Montreal, Canada, from March 2013 to June 2016, and who underwent motor evaluations at the ages of 4, 12 and 24 months were considered to be included in this study. Infants were excluded if they: (1) underwent cardiac repair after three months of age as this might have impacted the gross motor functioning at 4 months of age, (2) were diagnosed with a genetic syndrome that affects neurodevelopment, (3) were born preterm (<37 weeks gestational age), or (4) had incomplete assessments or a significant amount of missing data regarding physical therapy. Perinatal, surgical, critical and demographic variables were collected from medical records. Anatomic CHD classification[15] and surgical risk category[16] were extracted from the descriptions of cardiac lesions and surgical procedures. This study was conducted with the formal approval of the Research Ethics Board of the CHU Sainte-Justine and all families gave written informed consent for their participation (Ethical review committee: Research Ethics Board of the CHU Sainte-Justine; Approval number: 2015-806, 4024).

2.2. Gross motor evaluations and intervention

As part of their developmental follow-up, children's gross motor functioning was assessed using the Alberta Infant Motor Scale (AIMS)[17] at the age of 4 months ± 2 weeks, and the gross motor section of the Bayley Scales of Infant and Toddler Development, Third edition (Bayley-III/GM)[18] at 12 and 24 months ± 1 month. All motor evaluations were standardized; they were performed at

 doi:10.20944/preprints201908.0248.v1

4 months by physical therapists (LD and MM), at 12 months by occupational therapists (KG and JP), and at 24 months by a psychologist (MCV).

At 4 months of age, an individualized motor intervention programme was established if needed. Each programme was based on the severity of the impairment as appreciated using the AIMS – a score below the 10th percentile rank being considered as a high-risk score for motor delay – [19,20] and the physical therapists' observations. If needed, infants received early physical therapy at our neurocardiac clinic before they were referred to their regional paediatric centre at the age of 8 months at the earliest. Physical therapy sessions consisted of strengthening the muscles of the neck, chest and extremities to bring the child to assume and maintain anti-gravity positions such as bringing hands to midline in supine, holding the forearm prop position in prone and maintaining sitting. The sessions also included stimulating transitional movements such as rolling.

Infants of our cohort were divided into three groups according to their motor performance at 4 months and number of physiotherapy sessions received between the ages of 4 and 8 months: the *no-intervention* group (controls) performed equal or above the 10th percentile rank at the AIMS and received no intervention; the *occasional intervention* group performed below the 10th percentile rank on AIMS and received one or two therapy sessions; the *regular intervention* group performed below the 10th percentile rank on AIMS and received a minimum of three sessions. We quantified the number of physical therapy sessions received between 4 and 8 months of age exclusively because of our focus on early motor intervention and because of our inability to document the physiotherapy provided at regional paediatric centres after the age of 8 months.

2.3. Statistical analyses

Descriptive statistics were used to characterize the cohort as a whole and to describe each of the groups (*no-intervention* vs. *occasional intervention* vs. *regular intervention*). Frequencies (sample

 doi:10.20944/preprints201908.0248.v1

size and percentages) were reported for dichotomous and categorical variables. Median and inter-quartile ranges were reported for continuous variables. We performed a one-way repeated-measures analysis of variance (ANOVA) on Bayley-III/GM at 12 and 24 months with the interventional group as an inter-subject factor. Post-hoc tests using pair-wise comparisons were conducted to differentiate gross motor trajectories between the groups. Bonferroni corrections were applied when necessary. Significance level was set at $P < 0.05$.

3. Results and discussion

3.1. Sample population

A total of thirty (N = 30) infants were included in this pilot study: six (n = 6) infants in the *no-intervention* group, thirteen (n = 13) in the *occasional intervention* group, and eleven (n = 11) in the *regular intervention* group. Perinatal, surgical, critical and demographic characteristics of the cohort are presented in Table 1. The most common heart defects were transposition of the great arteries, coarctation of the aorta, ventricular septal defect, and double outlet right ventricle. The most represented anatomic CHD categories were classes I and II, that is two-ventricle hearts without arch obstruction (66.7%) and two-ventricle hearts with arch obstruction (20%). Surgical risk categories 2, 3, and 4 were represented in 10 (33.3%), 13 (43.3) and 7 (23.3%) cases, respectively. Median age at cardiac repair was 9.5 days (*ICR*: 6-26.5). Twenty (66.7%) infants required both cardiopulmonary bypass (CPB) and cross clamp (CC) during heart surgery, one (3.3%) required only CPB, six (20%) only CC, two (6.7%) did not require any mechanical support and one (3.3%) had missing data. Median paediatric intensive care unit (PICU) and hospital length stays were 5.5 and 19 days (*ICR*: 4-12.25 and *ICR*: 10-28). There was no difference in gestational age, birth weight, age at cardiac repair, duration of CPB or CC during cardiac surgery, anatomic

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CHD classification, surgical risk category, PICU and hospital length stay between groups. Infants of the *no-intervention* group had a lower Apgar score at 5 minutes (P = .009).

3.2. Motor functions and interventions

Out of 30 infants included in this study, six (20%) performed above the clinical cut-off at 4 months (≥ 10th percentile rank), and 24 (80%) were at risk of motor delay (< 10th percentile rank) and required physical therapy. The proportion of children with gross motor delay at the age of 4 months in our cohort was higher compared to Long and colleagues' study which reported that 36% of 4-months-olds had delayed gross motor development.[11] However, our results are overall in agreement with previously reported neurodevelopmental outcomes suggesting that gross motor impairments are common in this population.[2,4,5,9] These motor impairments may be associated with muscle tone anomalies, core or limb weakness or asymmetries such as a preferential cervical rotation to one side due to plagiocephaly or torticollis. These perturbations likely arise from a complex interplay between prenatal, surgical and environmental risk factors that lead to brain injury and dysfunction.[7,21,22] In fact, brain injury acquired during the foetal, the postnatal or the perioperative periods,[23–27] combined with a lack of motor experience,[28] were shown to contribute to these impairments.

Of the 24 (80%) infants of our cohort who presented gross motor delay and required additional care, 13 (54.2%) received one to two physical therapy sessions between the ages of 4 and 8 months, while 11 (45.8%) received three to six therapies. To the best of our knowledge, no study has quantified early motor interventions in infants with CHD. In older cohorts, the prevalence of children with CHD who used rehabilitation services largely exceeded that of healthy children.[29,30] Mussatto and colleagues reported that 74% of 3-year-old infants with CHD received intervention services from US regional early intervention programmes or private therapy,[4] and 53% of 5-year-

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old infants with CHD from the Paris area received at least one rehabilitation service in Calderon and colleagues' study.[29] Others indicate that 40% to 95% of 8-year-old children with CHD required relevant educational or rehabilitation services, but however they did not received these services.[30]

3.3. Gross motor trajectory between 12 and 24 months

The one-way repeated ANOVA revealed a significant increase in Bayley-III/GM scores between the ages of 12 (*Mdn* = 7, *IQR*: 6-9) and 24 months (*Mdn* = 9, *IQR*: 7-10; Wilk's Lambda, $F[1,27] = 6.233$, $P = .019$, $\eta_p^2 = .188$), suggesting an improvement of gross motor skills in our cohort, with scores being comparable to typically developing infants at 24 months of age. A similar gradual increase in motor abilities was previously reported up to 36 months of age in CHD children without genetic syndromes.[4,5] Interestingly, Mussatto and colleagues observed a gradual improvement in gross motor abilities – which were similar to a normative population at 12 months of age and older – in a cohort of children who received early intervention services in 74% of cases.[4] However, they could not determine whether this improvement was the result of a natural evolution or the early intervention following cardiac surgery. Sananes and colleagues did show a gradual improvement in gross motor development from 8 to 24 months of age, but motor skills remained below average.[5] However, there was no mention of early intervention or of potential access to physical therapy, which may explain the discrepancy with our results.

3.4. Effect of early individualised motor intervention

Figure 1 illustrates the trajectories of gross motor development in children with CHD as a function of interventional group between the ages of 4 and 24 months. The ANOVA results revealed a tendency for an effect of group (*no-intervention*, *occasional intervention*, and *regular intervention*) on the Bayley-III/GM scores (Wilk's Lambda, $F[1,27] = 3.037$, $P = .065$, $\eta_p^2 = .184$). Pairwise comparisons showed a marginally significant difference in gross motor functioning between the

 doi:10.20944/preprints201908.0248.v1

no-intervention and *regular intervention* groups (P = .051) at the age of 12 months. At this age, only one (17%) infant of the *no-intervention* group scored below normative values compared to six (55%) infants of the *regular intervention* group. This discrepancy reflects the initial gross motor impairment of infants in the *regular intervention* group as they were still receiving motor stimulation in regional paediatric centres after 8 months of age.

We found a significant increase in Bayley-III/GM scores between 12 (*Mdn* = 6, *IQR*: 2-7) and 24 (*Mdn* = 9, *IQR*: 6-10) months in the *regular intervention* group (P = 0.001), but no significant change for the *no-intervention* and *occasional intervention* groups (P = 0.753, and P = 0.096). Therefore, infants with motor delay at 4 months who received regular interventions showed improved gross motor scores from 12 to 24 months of age, with their performances being no different than the *no-intervention* group at 24 months (P = 1.00). Although at a trend level, these results suggest a benefit of early physical therapy on the developmental trajectory of gross motor skills in CHD children requiring early corrective surgery and at risk of developmental motor delay.

Very few studies have investigated the effect of interventions to improve neurodevelopmental outcome in children with CHD[31–33] and none of these studies addressed gross motor development. Nevertheless, literature on children at risk of impairment, such as preterm or low-birth-weight infants, brings growing evidence of the positive influence of early intervention on neurodevelopmental outcome.[34–36] A recent review and meta-analysis on preterm infants highlights the benefits of systematic interventions specifically targeting motor development, such as home or clinic-based motor exercises, and early physical therapy, compared to generic interventions.[35] Furthermore, interventions received before 12 months of age showed benefits up to the age of 24 months in preterm infants.[37] The programmes reviewed were offered to all infants regardless of their initial motor abilities; our patient-centred approach differs in that it provides

 doi:10.20944/preprints201908.0248.v1

psychoeducational support to parents and additional physical intervention sessions only as needed. Interventions that were shown to be the most effective at improving preterm infants' motor skills included supervising the child in practicing movements in supine, prone and side-lying positions, as well as facilitating hands to midline, which are taught in our clinic.[35] Finally, a recent study of our interdisciplinary team revealed that the ability to maintain the prone prop position in 4-months old infants with CHD resulted in an earlier onset of walking.[28] Altogether, these findings bring additional support to the idea that early motor experience may influence later motor development in high-risk populations and represents a modifiable factor that should be considered by health care professionals to optimize neurodevelopmental outcome.

3.5. Limitations

In an effort to reliably estimate the effects of early motor intervention, we attempted to control potentially cofounding factors and minimize the missing data using conservative inclusion/ exclusion criteria. For instance, we excluded infants who underwent cardiac repair after three months of age or had incomplete assessments. As a result, this study relied on a small sample size, which affects our statistical power and limits the generalizability of our results. These criteria may also have resulted in an over-representation of the most severe cases that may have been more likely to come back for developmental screening. Finally, this study focused on interventions provided to infants with CHD aged between 4 and 8 months of age at our clinic but could not estimate services provided later at regional paediatric centres.

In summary, this pilot study described the trajectory of gross motor development in infants with CHD included in an early and systematic developmental screening programme. We showed an improvement in gross motor development from 4 to 24 months of age in our patient group. Regular physiotherapy sessions seemed to help to improve gross motor skills in infants at risk of

motor delay. Although at a trend level, these results may suggest a beneficial effect of participating in such an early and structured programme. They also highlighted the importance of performing the early motor skills' surveillance in infants with CHD who underwent cardiac repair in order to identify early those with a delay in development to provide individualized interventions. Large clinical trials are needed to confirm findings and further quantify the benefits of early intervention.

Acknowledgments
The authors warmly thank all the participating families, as well as the staff of the *Clinique d'Investigation Neurocardiaque* (CINC) of the CHU Sainte-Justine, Montreal, QC, Canada.

Funding sources
This work was supported by the Heart and Stroke Foundation of Canada under grant number G-16-00012606, the *Fonds de la Recherche du Québec – Santé* (FRQS) under grant number 28811, and the Canadian Institutes of Health Research (CIHR) under grant number NI203422 held by AG.

Declaration of interest
The authors declared no interests which may be perceived as posing a conflict or bias.

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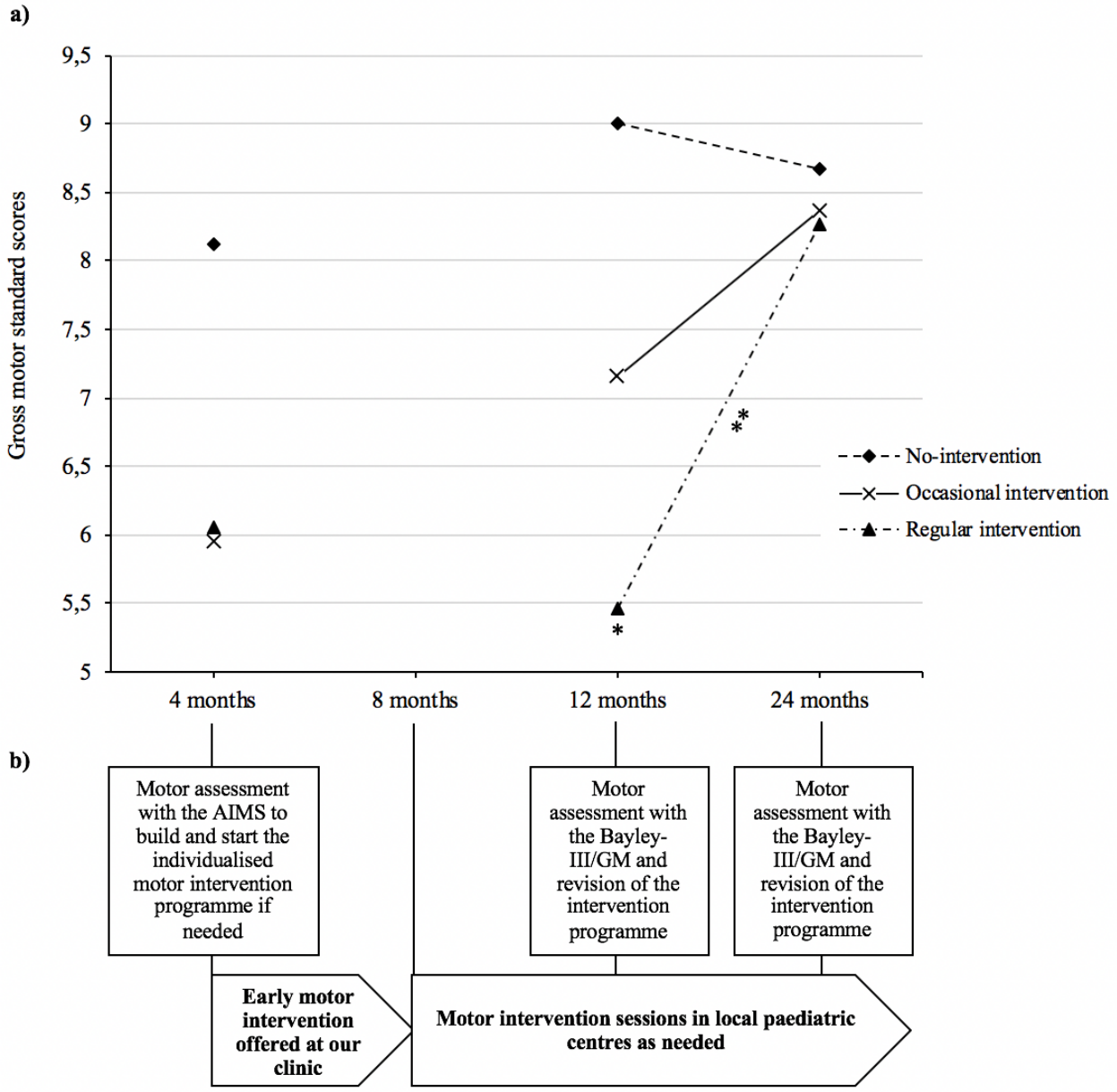

Figure 1. a) Developmental gross motor trajectory from 4 to 24 months of age in groups of infants with CHD: *no-intervention* group (control; dotted line), *occasional intervention* group (plain line), and *regular intervention* group (dashed line). Gross motor functions were evaluated with the AIMS at 4 months (percentile ranks converted into standard scores), and with Bayley-III/GM at 12 and 24 months.
b) Timeline of standardised motor assessments and individualised intervention at the CHU Sainte-Justine *Clinique d'Investigation Neurocardiaque* (CINC).
* indicates statistical trend to significant differences between *no-intervention* and *regular intervention* groups ($P = .051$)
** indicates significant increase in gross motor performances for the *regular intervention* group ($P = .001$)

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Table 1. Clinical and demographical characteristics of infants with congenital heart disease (CHD). Frequencies (sample size and percentages) were reported for dichotomous and categorical variables. Median and interquartile ranges were reported for continuous variables.

	Groups			
	No-intervention (n = 6)	Occasional intervention (n = 13)	Regular intervention (n = 11)	Total (N = 30)
Male sex, n	4 (66.7)	10 (76.9)	6 (54.5)	20 (66.7)
Prenatal diagnosis, n	4 (67)	5 (38.5)	3 (27.3)	12 (40)
Gestational age at birth, wk	39.93 (38.75-40.46)	38.86 (38-40-07)	39.00 (38.29-39.86)	39 (38.22-40.04)
Birth weight, kg	3.056 (3.19-3.74)	3.15 (2.97-3.56)	3.46 (2.79-3.88)	3.31 (3.00-3.68)
Apgar score at 5 min	8 (7.25-8.75)	9 (8-9)	9 (8.75-10)	9 (8-9)
Anatomic CHD classification, n[b,1]				
Class I	5 (83.3)	7 (53.8)	8 (72.7)	20 (66.7)
Class II	1 (16.7)	4 (30.8)	1 (9.1)	6 (20)
Class III	0 (0.0)	1 (7.7)	1 (9.1)	2 (6.7)
Class IV	0 (0.0)	1 (7.7)	1 (9.1)	2 (6.7)
Corrective surgery				
Age at surgery, d	8 (5.75-11.25)	11 (8-22)	8 (4-63)	9.5 (6-26.5)
CPB, n[b]	5 (83.3)	10 (76.9)	6 (60)	21 (72.4)
CPB time, min[b]	163 (40.50-184.25)	159 (42.5-204)	79 (0-154.25)	152 (0-185.5)
CC, n[b]	6 (100)	12 (92.3)	8 (80)	27 (89.7)
CC time, min[b]	108 (37.25-127.25)	75 (18.5-135.5)	32.5 (13.5-95.65)	75 (18.5-119.5)
Hospital length stay, d	13 (10-19.75)	25 (11.50-31)	16 (8-16)	19 (10-28)
PICU length stay, d	3.5 (2.25-4)	7 (5-13.50)	5 (4-10)	5.5 (4-12.25)
Surgical risk category, n[2]				
Category 2	2 (33.3)	4 (30.8)	4 (36.4)	10 (33.3)
Category 3	3 (50)	6 (46.2)	4 (36.4)	13 (43.3)
Category 4	1 (16.7)	3 (23.1)	3 (27.3)	7 (23.3)
Maternal education level, n[c]				
High school	1 (25)	3 (25)	6 (54.5)	10 (37)
Vocational school	2 (50)	4 (33.3)	1 (9.1)	7 (26)
College/university	1 (25)	5 (41.7)	4 (36.4)	10 (37)
Neurodevelopmental outcome[d]				
4-months AIMS	7.03 (6.61-10.38)	5.95 (5.95-5.99)	5.95 (5.95-6.03)	5.95 (5.95-6.41)
12-months Bayley-III/GM	8 (6.75-12.25)	7 (6.25-9)	6 (2-7)	7 (6-9)
24-months Bayley-III/GM	9 (8-9)	10 (7-10)	9 (6-10)	9 (7-10)

Abbreviations: CHD, congenital heart disease; CPB, cardiopulmonary bypass; CC, cross clamp; PICU, paediatric intensive care unit; AIMS, Alberta Infants Motor Scales; Bayley-III/GM, gross motor scale of the Bayley Scales of Infant and Toddler Development, Third edition.

[b] One missing data in the intervention group.

[c] Two missing data in the *no-intervention* group, one missing data in the *occasional intervention* group.

[d] Neurodevelopmental outcome is expressed as standard scores.

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