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Neuropsychological Status in Children After Repair of Acyanotic Congenital Heart Disease

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Abstract

OBJECTIVES—The majority of previous studies that described the neuropsychological effects of cardiopulmonary bypass (CPB) in children were performed after surgery in infancy for complex congenital heart disease (CHD). We sought to limit confounding variables and isolate potential independent effects of CPB by describing neuropsychological function in school-aged children after repair of acyanotic CHD.

METHODS—This was a prospective study of patients who were aged 5 to 18 years and undergoing repair of acyanotic CHD. Neuropsychological testing battery included assessment of intelligence, memory, motor, attention, executive function, and behavior before and 6 months after

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CPB. The independent effects of anesthesia, surgery, and hospitalization on neuropsychological function were assessed by testing a surgical control group of patients who were undergoing repair of pectus deformities. In addition, an outpatient group of children with mild CHD were enrolled to assess the practice effects of serial testing.

RESULTS—Patients included CPB (n = 35), surgical control (n = 19), and nonsurgical (n = 12). Groups were comparable in age, gender, and race and demonstrated similar unadjusted group mean scores on baseline and 6-month follow-up neuropsychological testing. When adjusted for practice effects, the CPB group performed similar to the non-CPB groups in all assessed neuropsychological domains, with the exception of 1 of 4 tests of executive function.

CONCLUSIONS—When controlling for the non-CPB effects of surgery (eg, hospitalization, anesthesia, thoracotomy) and the practice effects of serial testing, there were no consistent independent effects of CPB on neuropsychological status in a cohort of children and adolescents 6 months after repair of acyanotic CHD.

Keywords

congenital heart disease; neuropsychological; central nervous system; cardiopulmonary bypass; cognition; behavior

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Cardiopulmonary bypass (CPB) has been implicated as a causative factor in abnormal neurocognitive outcomes after cardiac surgery.[1,2] Most studies of children that described these abnormalities were performed after surgery in infancy for complex congenital heart disease (CHD).[3–8] Multiple confounding risk factors for cognitive decline have been described in children with complex CHD, including a relatively high incidence of genetic syndromes, abnormal brain development, perinatal instability, and need for multiple operations.[9,10] Consequently, it has been difficult to delineate the relative contributions of CPB and intraoperative support on long-term CNS abnormalities in this population.

To date, a limited number of studies have described the impact of CPB in school-aged children with acyanotic CHD, and these reports demonstrated somewhat conflicting results.[11–13] The primary aim of our study was to assess prospectively the neuropsychological impact of CPB on asymptomatic, school-aged children with isolated, acyanotic CHD in an effort to minimize confounding variables of infant CHD studies. We hypothesized that children who undergo CPB for correction of CHD will evidence greater declines in tested neuropsychological domains (eg, memory, motor, attention) when compared with a control group of aged-matched children who do not have CHD and undergo noncardiac surgery.

METHODS

Study Design

We performed a prospective cohort study to compare pre-CPB and post-CPB neuropsychological status in children with uncomplicated CHD with an age-matched surgical control group. We enrolled 3 study groups: group 1 (CPB+) included children who had acyanotic CHD and were undergoing surgery by using CPB; group 2 (CPB−) included children who had pectus deformities and were undergoing surgical repair; group 3 (outpatient reference group) included children who had mild acyanotic CHD and were not undergoing surgery. All 3 groups underwent the same NP and neurologic assessment by using a 6-month testing interval.

Patient Selection and Criteria

Between January 2004 and June 2007, surgical patients were identified by review of the operating room schedule at the Children's Hospital of Philadelphia. Inclusion criteria for the CPB+ group were diagnosis of acyanotic CHD with planned surgical repair by using CPB, age between 5 and 18 years, English speaking, informed consent from parents or guardians, and patient assent when appropriate. We excluded patients with previous CPB, documented genetic syndromes, and structural brain abnormalities associated with cognitive disability; those currently under treatment for a diagnosed psychiatric illness or attention-deficit/ hyperactivity disorder; symptomatic patients who met class 2 or higher New York Heart Association criteria; and a history of general anesthesia <14 days before the first study testing date. To control for the independent effects of CPB, we simultaneously enrolled age matched patients who were undergoing surgical correction of pectus excavatum or carinatum. These patients were scheduled to undergo pectus repair with thoracic incision with a similar anesthetic, duration of hospitalization, and pain management strategy.

Because most conventional neuropsychological tests are not designed for serial testing, an individual's test scores may improve with repeated assessment as a result of increased test familiarity. We therefore enrolled a third group (outpatient reference group) that consisted of age-matched patients who had mild acyanotic CHD and were not scheduled for surgical repair. These patients were administered, at a 6-month interval, the same testing battery as the 2 surgical groups. This reference group was used to estimate the "practice effects" of serial testing and was not used in group comparisons. The protocol was approved by the institutional review board of the Children's Hospital of Philadelphia.

Neuropsychological and Neurologic Assessment

An in-depth neuropsychological battery was administered by a pediatric psychometrician to all enrolled patients 1 to 14 days before and ~6 months after surgery. Outcome domains included memory, motor, attention, executive function, intelligence, visual-motor integration, and behavior. In addition, enrolled patients underwent a complete examination by a pediatric neurologist. The psychometrician and neurologist both were blinded to patient diagnosis and group assignment. Details regarding neuropsychological testing battery and neurologic examination are provided in the Appendix.

Chart Review

Patient charts were reviewed for potential risk factors for abnormal neuropsychological outcome. Patient-related factors of interest included diagnosis, gender, ethnicity, and age at surgery. Intraoperative factors collected included procedure time (ie, time in the operating room), total CPB time, cross-clamp time, minimum hematocrit level, minimum nasopharyngeal temperature, and minimum pH. Postoperative risk factors of interest included duration of mechanical ventilation, length of ICU stay, length of hospitalization, and the presence of significant postoperative cardiovascular, respiratory, hematologic, CNS, and infectious events.

Statistical Analysis

Data analysis proceeded in 4 distinct phases. First, descriptive statistics were calculated for all variables in the data set, including measures of central tendency, variability, and association. Box plots were generated for visual comparison of the preoperative and postoperative test scores. Second, a series of regression-based analysis of covariance models were specified and tested for evaluation of differences in postoperative neuropsychological functioning between the 2 surgical treatment groups (CPB+ compared with CPB− patients), after adjustment for level of preoperative functioning and state-trait anxiety score. Postoperative scores were adjusted for both practice effect and instrument reliability to account for measurement error by using the Reliability-Stability Index (RSI).[14] RSI scores were derived for each of the following 8 measures representing 6 areas of neuropsychological functioning: memory (Buschke Selective Reminding Test [BSRT], Benton Visual Retention Test [BVRT]), motor skills (Grooved Pegboard), attention/executive function (Attention/Concentration Index, Tower of London-Drexel Version [TOL-DX]), general intelligence (Wechsler Abbreviated Scale of Intelligence [WASI]), visual-motor integration (Beery-Buktenica Developmental Test of Visual-Motor Integration, Fourth Edition Revised [VMI]), and behavior (Behavior Assessment System for Children: Parent Rating Scales [BASC]). Such an adjustment was deemed necessary given potential threats to validity often attributed to unreliability of measures and effects of repeated testing with the same instruments over relatively short intervals. Raw neuropsychological data were converted to standard scores for all tests except the domain of memory (BVRT and BSRT). For BVRT and BSRT, raw data were presented and analyzed because normative values do not exist for a significant number of patients at ages enrolled in this study. For these 2 measures, with only raw scores available, test age was used as a covariate in the predictive models. In addition, models for percentage change for these 2 raw scores were tested to verify the results from models by using the RSI. Third, a descriptive analysis was performed by using change scores relative to 1 SD as a follow-up of our models and for better understanding of changes at the individual level. Here, we describe the number (%) of patients in each group who improved 1 SD, showed no change (ie, stayed between +1 and −1 SD), or declined 1 SD on postoperative testing. Finally, risk models were specified and tested by using patient-related variables (age, race, gender, and socioeconomic status [SES]), and operative-related variables (duration of mechanical ventilation, presence of adverse events, and length of hospital stay). The model development steps were conducted first by testing single covariate models, and then multiple covariate models were specified by using the statistically significant covariates with backward selection procedures.

With the sample size enrolled in this study, we had 80% power to detect a 1-SD change in postoperative scores. One SD is a degree of change that was considered clinically significant in previous reports of postoperative neuropsychological decline.

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RESULTS

Study Population

During the enrollment period, there were 64 eligible CPB+ patients, 41 (64%) of whom consented for participation and underwent baseline study testing. Reasons for failure to enroll included living out of state ($n = 12$), unavailability of psychometrician ($n = 6$), and unwillingness to participate ($n = 5$). The diagnoses of the CPB+ group are described in Table 1. There were no deaths in this cohort, and 6 patients did not return for follow-up testing. Reasons for failure to return for postoperative testing included refusal to travel from out of state ($n = 4$) and loss to follow-up ($n = 2$). There were no differences in baseline parameters between returners and nonreturners.

During the same enrollment period, there were 46 eligible CPB− patients. Of these, 21 (45%) consented to participate and underwent study testing. All underwent repair of either pectus excavatum ($n = 20$) or pectus carinatum ($n = 1$). There were no deaths, and 2 patients were lost to follow-up. Finally, we enrolled 15 outpatient reference patients, 3 of whom did not return for final study testing.

There were no significant differences in demographic variables such as age, race, gender, ethnicity, SES scores, and need for special education services among the 3 groups (Table 1). Intraoperative variables for the CPB+ group are shown in Table 2. Two patients required a second period of CPB, and there was 1 reoperation for mediastinal bleeding. Postoperative variables for both CPB+ and CPB− groups are shown in Table 3. In the CPB+ group, there were 7 significant postoperative events: pericardial effusion that required drainage ($n = 3$), ventricular tachycardia ($n = 2$), mediastinitis ($n = 1$), and chylothorax ($n = 1$). In the CPB− group, there was a postoperative-related infection in 1 patient.

Neuropsychological Assessment

At baseline, all 3 groups performed within normal limits on neuropsychological testing, and there were no significant differences in scores (Table 4). Higher scores represent better performance in all reported test results except for Behavior Symptoms T Score of the BASC. Unadjusted group mean scores were similar between the 2 surgical groups before and after surgery, with slight trends toward postoperative improvement. We initially tested our models for an effect of state anxiety by using the State-Trait Anxiety Inventory for Children, but because anxiety had no effect on any of the outcomes, it was dropped from additional analysis. Comparison of RSI-adjusted mean pre–post change scores demonstrated a statistically significant difference between the 2 surgical groups on only 1 of 8 neuropsychological tests, the total move score of the TOL-DX. In this test of executive function, the CPB+ patients demonstrated less improvement on post-operative testing when compared with CPB− patients. A limited number of follow-up analyses were performed on additional TOL-DX measures for better assessment of executive function. These included the total correct score, total rule violations score, and the total initiation time score. No statistically significant differences between the groups were found on any of these measures.

Table 5 is a descriptive illustration of change scores for individuals in both the CPB+ and CPB− groups. There were similar numbers of patients in both groups who improved (>1

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SD), showed no change (stayed between +1 and −1 SD), or declined (>1 SD) on postoperative testing. This is further displayed in Fig 1, a representative scatter plot of individual-level test scores, which demonstrates the patient variability despite that group mean scores remained within normal ranges. There are patients in each group who demonstrated decline and improvement. We could not identify patient, procedure, or postoperative variables to account for these changes.

Neurologic Examinations

Preoperative and postoperative neurologic examinations were performed on 23 CPB+ and 11 CPB− patients. Of the 23 CPB+ evaluations, 21 had normal neurologic status on both examinations. One CPB+ patient was scored abnormal pre-operatively and scored as normal post-operatively, and the other CPB+ patient was scored as suspect on both evaluations. All 11 CPB− patients tested had normal neurologic examinations before and after surgery.

DISCUSSION

In the past, the decision to recommend surgery for children with acyanotic CHD was largely on the basis of the risks of surgery compared with the potential hemodynamic benefits; however, with the advent of transcatheter options for certain defects (eg, septal defects, valve replacement), the risk-to-benefit ratio of surgery in this subgroup of patients needs to be reevaluated, specifically related to the effects of CPB on the CNS. Thus, we enrolled a group of healthy school-aged children with acyanotic CHD and performed an in-depth neuropsychological battery before and 6 months after CPB. The diverse neuropsychological battery was selected to assess specific domains that were demonstrated in previous studies to be most likely affected by CPB.[1–8] A period of 6 months was used to assess postoperative status on the basis of previous studies that documented an approximate 50% incidence of transient neuropsychological abnormalities in the early weeks after CPB, anesthesia, and pain medication use.[1,2,15] We compared the testing results with those of an age-matched group of children who underwent repair of pectus deformities. When comparing the groups, we found no significant postoperative decline in neuropsychological performance between the groups in unadjusted mean scores. As expected, we saw trends toward mild improvement in postoperative scores in both groups, which is likely attributable to the practice effect of serial testing. After adjusting pre–post change scores for these potential practice effects and test–retest reliability, we found no significant differences between CPB+ and CPB− groups in the domains of memory, attention, fine or gross motor, general intelligence, visual motor integration, or behavior. We found a small but statistically significant difference between the CPB+ and CPB− groups in the adjusted pre–post change scores in 1 test of executive function. It is important to note that scores for both groups were within normal range at baseline and showed increases post-operatively; however, as a result of the larger increase in scores in the CPB− group, the adjusted pre–post change scores revealed a statistically significant difference between the groups. Executive function is a measure of integration of intellectual activities, which includes planning and organizational skills. In an effort to understand more fully the potential impact of CPB on executive function, we conducted a limited number of follow-up comparisons on related TOL-DX measures, including the total correct score, total rule violations score, and the total initiation time score. After failing to

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observe any additional statistically significant differences between groups, we suspect that the lone total move RSI score is likely an isolated finding and a statistical artifact rather then a clinically relevant finding. Nonetheless, abnormalities in this neuropsychological domain have been demonstrated in survivors of surgery in the neonatal period for more complex CHD and may require additional study.

Although mean scores provide important information regarding the performance of a group, an understanding of individual change is helpful to assess a child's individual risk for cognitive decline. In our description of individual change, there was a similar spread of children across categories in both surgical groups. It is interesting that there was significant individual variability in test scores in both surgical groups. We found that some CPB− patients demonstrated mild to moderate postoperative cognitive decline (>1 SD), suggesting that factors other than CPB are responsible, such as hospitalization, anesthesia, and stress. Our work supports the recent findings that were seen in adults who underwent coronary artery bypass grafting. Selnes et al[16] randomly assigned patients who were undergoing coronary artery bypass grafting to either on- or off-CPB techniques and demonstrated a similar degree of cognitive decline in both groups after repair, suggesting an important role for non-CPB factors. As in adult patients with acquired heart disease, we have also shown that postoperative neuropsychological decline in some patients occurs in the absence of CPB.

Previous studies that described cognitive outcomes in school-aged children who underwent repair of acyanotic defects are limited. Visconti et al[11] compared neurocognitive function of 26 children after surgical atrial septal defect (ASD) closure with a group of 19 children who underwent transcatheter device closure and reported a deficit in Full-Scale IQ in the surgical group; however, this was a retrospective study that lacked preintervention testing, and both parental IQ and maternal education were higher in the transcatheter group, likely affecting results. Stavinoha et al[12] prospectively administered the Differential Ability Scales to 18 children before and after surgical ASD repair. No postoperative declines were found, but this was a relatively small cohort, with a limited testing battery and no control group. More recently, Van der Rijken et al[13] performed neurocognitive testing before and 1 year after surgery in a heterogeneous cohort of school-aged children, including some children with more complex CHD involving previous surgeries with CPB. The investigators reported no differences between the study groups when compared with a nonsurgical control group that was composed of children who underwent transcatheter ASD closure. For asymptomatic children with acyanotic CHD, our study expands on previous reports by including a surgical control group (pectus deformities) and adjustment for practice effects of serial testing. As with previous reports, we found that surgery for acyanotic CHD by using CPB results in a variable pattern of neurocognitive changes, but significant deterioration was uncommon and could not be specifically attributed to CPB. In addition, our study was different from previous efforts in that we excluded children with previous CPB exposure or other potential confounders, such as genetic syndromes.

This study was limited because only a small number of patients had a significant decline in postoperative testing. This precluded an analysis of potential risk factors for neuropsychological decline. It is possible that a larger sample size would have yielded different results. For additional exploration of these findings and definition of potential risk factors for neuropsychological decline, a larger multi-institutional study would be necessary. Second, in an effort to minimize confounding variables and isolate potential effects of CPB, we purposely enrolled a cohort of healthy children who had uncomplicated CHD and underwent straightforward bypass (ie, relatively brief periods of mildly hypothermic CPB); therefore, these results are not generalizable to other groups of children and neonates who undergo longer periods of hypothermic CPB. Finally, because we performed postoperative testing at a 6-month interval, we are not yet able to assess the long-term status of these patients.

CONCLUSIONS

When controlling for the potential risk factors of anesthesia, surgery with chest wall incision, hospitalization, anxiety, and the practice effects of serial testing, we found no clear independent effects of CPB on neuropsychological status 6 months after repair of acyanotic CHD. Mild postoperative cognitive decline may occur in children after hospitalization and surgery but is not specifically attributable to CPB. Potential neuropsychological sequelae of CPB in this group of children and adolescents at low risk should not be a major factor in the decision to recommend surgical intervention for acyanotic CHD in childhood.

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ABBREVIATIONS

CPB	cardiopulmonary bypass
CHD	congenital heart disease
RSI	reliability stability index
BSRT	Buschke Selective Reminding Test
BVRT	Benton's Visual Retention Test
TOL-DX	Tower of London, Drexel Version
WASI	Wechsler Abbreviated Scale of Intelligence
VMI	Berry-Buktenica Developmental Test of Visual-Motor Integration
BASC	Behavior Assessment System for Children: Parent Rating Scales
SES	socioeconomic status

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ASD atrial septal defect

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APPENDIX

Neuropsychological Assessment

The BSRT was used to measure verbal learning and memory during a multiple-trial list-learning task.[17] Visual memory was tested by the BVRT, which is designed to assess visual memory along with visual perception and visual-constructive abilities.[18] Fine motor function was tested with the Grooved Pegboard.[19] The purpose of this test is to measure fine motor speed and hand dexterity through the use of a small pegboard with grooved pegs that must be fitted into slotted holes. The test is scored in terms of completion time. Attention and executive function was assessed by the attention/ concentration index from the Children's Memory Scale.[20] This test is designed to assess the ability to sustain and direct attention, concentration, processing speed, and working memory. In addition, we assessed executive function with the TOL-DX, which is designed to measure higher order problem-solving, specifically executive planning and organizing abilities.[21] General intelligence was assessed by the WASI.[22] The WASI is a brief but reliable measure of verbal performance and overall intelligence. The WASI consists of 4 subtests chosen for their strong association with scores on more extensive test measures of intellectual ability. Visual-motor skills were assessed with the VMI.[23] The VMI is designed to assess the extent to which individuals can integrate their visual and motor abilities by presenting a sequence of increasingly complex designs that are copied with paper and pencil. Behavior was assessed by the BASC.[24] The BASC questionnaire evaluates adaptive and clinical behaviors of children.

Additional demographic and patient data were collected. The Hollingshead form supplemented with a socioeconomic questionnaire was used to assess family background, including marital status, parental education level, employment status, and yearly income.[25] An SES score of 1 to 5 was created on the basis of responses, with a higher score indicating higher family status. Questions regarding racial and ethnic backgrounds were also obtained. A pediatric history form, completed by the child's caregivers, was created to gather patient information between testing sessions that could potentially affect neuropsychological status such as medication changes, recent hospitalizations, and the onset of new symptoms. Finally, the State-Trait Anxiety Inventory for Children was administered to measure the temporary condition "state anxiety" and the more general and long-standing quality of "trait anxiety,"

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because patient anxiety can adversely affect neuropsychological testing performance (Fig 2).[26]

Neurologic Assessment

In addition to a neuropsychological assessment, enrolled patients underwent a complete neurologic examination that focused on the assessment of cranial nerve function, symmetry of limb movement, passive tone, deep tendon reflexes, and plantar responses. A general neurologic impression was assessed as abnormal when there was a fixed neurologic deficit, suspect when there were soft signs such as slowed rapid alternating movements, or normal.

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WHAT'S KNOWN ON THIS SUBJECT

Cardiopulmonary bypass has been implicated as a causative factor in abnormal neurocognitive outcomes following cardiac surgery. Most studies in children describing these abnormalities have been performed following surgery in infancy for complex congenital heart disease.

WHAT THIS STUDY ADDS

Prospective assessment of the neuropsychological status in children after repair of acyanotic CHD. Unique study design with enrollment of control groups, we provide evidence that mild cognitive decline may occur after surgery but is not specifically attributable to CPB.

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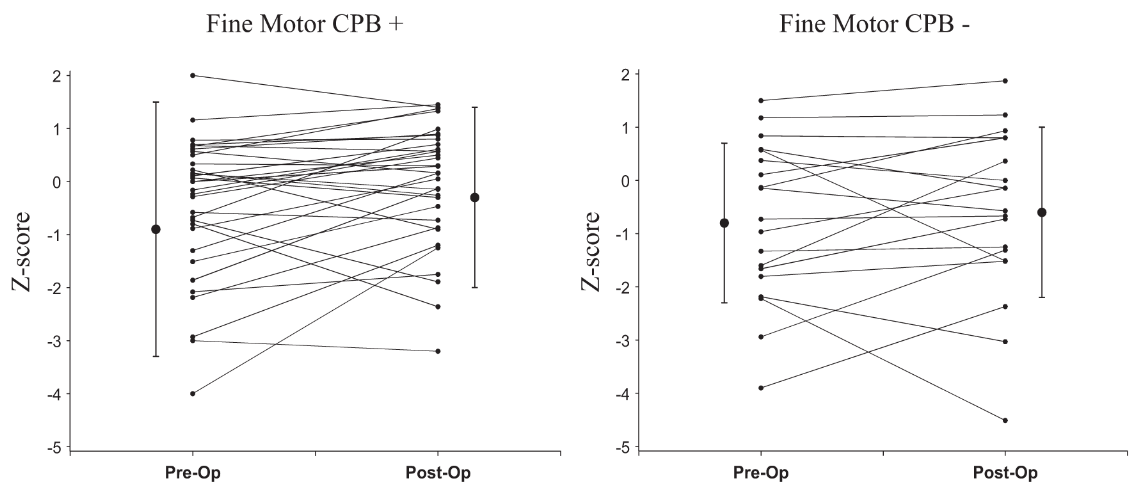

FIGURE 1.

Individual preoperative and postoperative test scores for CPB+ and CBP− patients for the grooved pegboard, preferred hand time *z* score. The large solid circles and error bars represent mean and SD.

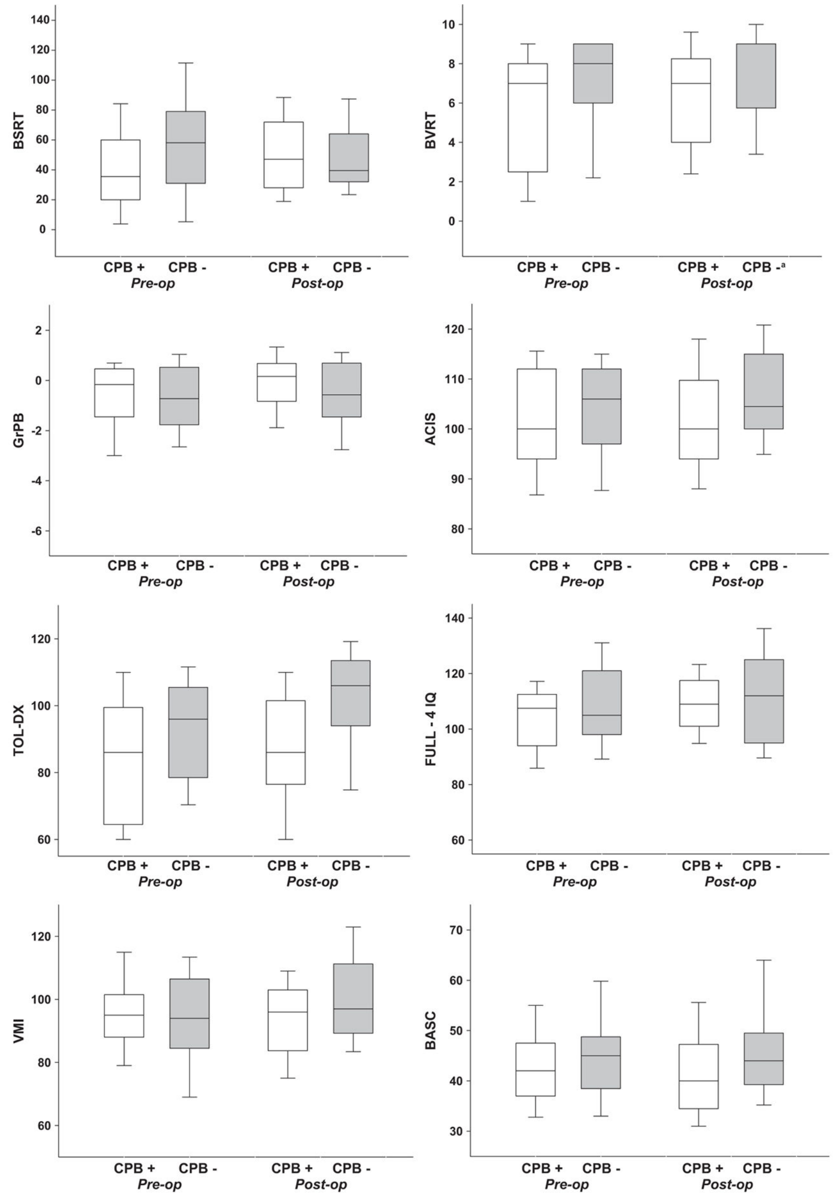

FIGURE 2.

The box plots of the neuropsychological test scores represent the 25th percentile, median, and 75th percentile. The whiskers above and below the box indicate the 90th and 10th percentiles. GrPB indicates grooved pegboard; ACIS, Children's Memory Scale, attention/concentration index.

[a]For the CPB− patients the median and 75th percentile for BVRT are equal.

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TABLE 1

Characteristics of Enrolled Study Patients

Characteristic	CPB+ (*n* = 41)	CPB− (*n* = 21)	Nonsurgical (*n* = 15)	*P*
Diagnoses				
ASD	17		3	
Anomalous coronary	8			
VSD	6		3	
Aortic valve disease	5		7	
Mitral valve disease	3		2	
Double-chambered right ventricle	1			
Hypertrophic cardiomyopathy	1			
Pectus excavatum		20		
Pectus carinatum		1		
Other	5			
Age, mean ± SD, y	11.8 ± 4.0	12.4 ± 3.0	10.4 ± 4.0	.5
Male gender, %	54	74	44	.1
White race, %	67	88	69	.3
Special education, %[a]	7	5	12	.8

VSD indicates ventricular septal defect.

[a]Requires special education services.

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TABLE 2

CPB+ Group Intraoperative Variables

Parameter	Value
Total procedure time, min	167 ± 38
CPB time, min	46 ± 21
Cross-clamp time, min	32 ± 19
Minimum hematocrit, mg/dL	24 ± 3
Minimum temperature, NPh, °C	33 ± 3
Minimum pH	7.38 ± 0.07

Data are means ± SD. NPh indicates nasopharyngeal.

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TABLE 3

Surgical Group Postoperative Descriptives

Parameter	CPB+ Group	CPB− Group
Length of ICU stay, mean ± SD, d	2.1 ± 0.9	0.3 ± 0.3
Length of hospital stay, mean ± SD, d	3.1 ± 1.5	4.4 ± 0.8
Duration of mechanical ventilation, median (range), h	0.50 (0.00–7.00)	0.00 (0.00–0.75)

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TABLE 4

Study Patients' Neuropsychological Test Scores

Test (Normative Values)	*n*	Preoperative	Postoperative	Δ Score	RSI *P*[a]
Grooved pegboard, preferred hand time, *z* score (mean = 0, SD = 1)					
CPB+ group	35	−0.9 ± 2.4	−0.3 ± 1.7	0.7 ± 1.5	.180
CPB− group	19	−0.8 ± 1.5	−0.6 ± 1.6	0.1 ± 1.1	
Outpatient reference	12	−0.7 ± 1.3	0.1 ± 1.3	0.8 ± 1.3	
ACIS, index score, standard score (mean = 100, SD = 15)					
CPB+ group	33	102 ± 13	101 ± 12	−1 ± 13	.380
CPB− group	18	105 ± 12	107 ± 12	2 ± 7	
Outpatient reference	12	102 ± 11	99 ± 15	−4 ± 10	
TOL-DX, total moves, standard score (mean = 100, SD = 15)					
CPB+ group	35	86 ± 20	87 ± 16	1 ± 21	.003
CPB− group	19	94 ± 16	102 ± 16	8 ± 19	
Outpatient reference	12	84 ± 18	101 ± 14	17 ± 22	
Intelligence, WASI Full-4 IQ, standard score (mean = 100, SD = 15)					
CPB+ group	32	104 ± 12	109 ± 11	5 ± 9	.950
CPB− group	18	109 ± 16	112 ± 18	3 ± 9	
Outpatient reference	12	102 ± 9	103 ± 10	1 ± 10	
VMI, standard score (mean = 100, SD = 15)					
CPB+ group	35	95 ± 13	94 ± 13	−1 ± 13	.130
CPB− group	19	95 ± 17	100 ± 14	5 ± 12	
Outpatient reference	12	99 ± 12	92 ± 16	−7 ± 10	
BASC, behavior symptoms, *t* score (mean = 50, SD = 10)[b]					
CPB+ group	29	43 ± 9	42 ± 9	−1 ± 7	.190
CPB− group	19	46 ± 10	47 ± 12	1 ± 9	
Outpatient reference	12	47 ± 10	48 ± 9	1 ± 6	
BVRT, number correct, raw score (range: 4–8)					
CPB+ group	29	5.5 ± 3.0	6.3 ± 2.8	0.8 ± 2.3	.910
CPB− group	17	6.9 ± 2.6	7.5 ± 2.5	0.6 ± 1.8	
Outpatient reference	10	5.6 ± 3.0	5.6 ± 2.6	0.0 ± 2.4	

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Test (Normative Values)	*n*	Preoperative	Postoperative	Δ Score	RSI *P*[a]
BSRT, long-term recall, raw score (range: 19–45)					
CPB+ group	34	41 ± 28	51 ± 29	11 ± 24	.080
CPB− group	18	56 ± 36	50 ± 30	−7 ± 35	
Outpatient reference	10	48 ± 30	42 ± 36	−6 ± 29	

Data are means ± SD. ACIS indicates Children's Memory Scale, attention/concentration index.

[a]Adjusted *P* value for pre–post change scores between 2 surgical groups.

[b]Higher scores represent better performance in all administered tests except for Behavior Symptoms Index.

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TABLE 5

Surgical Group Individual Change Scores

Neuropsychological Test	CPB+ (*n* = 35), *n* (%)			CPB− (*n* = 19), *n* (%)		
	Improved	**Unchanged**	**Worse**	**Improved**	**Unchanged**	**Worse**
Grooved pegboard	3 (9)	32 (91)	0 (0)	0 (0)	18 (95)	1 (5)
ACIS	1 (3)	28 (85)	4 (12)	1 (6)	16 (89)	1 (6)
TOL-DX	10 (29)	17 (49)	8 (23)	5 (26)	11 (58)	3 (16)
VMI	5 (14)	25 (71)	5 (14)	5 (26)	14 (74)	0 (0)
Full-IQ	7 (22)	25 (78)	0 (0)	2 (11)	15 (83)	1 (6)
BASC	1 (3)	27 (93)	1 (3)	2 (11)	16 (84)	1 (5)

Improved=>1 SD improvement on postoperative testing; unchanged > stayed between +1 and −1 SD on postoperative testing; worse=>1 SD decline on postoperative testing. ACIS indicates Children's Memory Scale, attention/concentration index.