Neuropsychological Performance in School-Aged Children with Surgically Corrected Congenital Heart Disease

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Objective As surgical management of children with congenital heart disease (CHD) advanced, developmental outcome became the main focus of contemporary research. In this study, we specify the cognitive profile of children with CHD, 6 to 12 years postoperatively.

Study design Patients with CHD (n = 43, mean age 8 years, 8 months) and healthy controls (n = 43, mean age 8 years, 11 months), were examined with an abbreviated intelligence scale (Wechsler Intelligence Scale for Children-3rd edition, Dutch version) and a developmental neuropsychological assessment battery (NEPSY [a developmental NEuroPSYchological assessment]).

Results We identified significantly lower scores for the CHD group on Estimated Full Scale IQ ($P < .01$). Neuropsychological assessment revealed lower scores for the CHD group on the cognitive domains of Sensorimotor Functioning ($P < .001$), Language ($P < .001$), Attention and Executive Functioning ($P < .05$), and Memory ($P < .05$). Children with CHD displayed more impulsive test behavior than healthy peers. No differences on IQ or cognitive domains were found between the cyanotic and the acyanotic CHD group.

Conclusions Six to 12 years postoperatively, children with CHD display a neuropsychological profile with mainly mild motor deficits and subtle difficulties with language tasks. Attention/executive functioning and memory also appear involved but to a lesser degree. Long-term follow-up of children with surgically corrected CHD, even when hemodynamically successful, is warranted, as they are at risk for neurodevelopmental delay at school age. *(J Pediatr 2007;151:73-8)*

The incidence of congenital heart disease (CHD) in the Western industrialized world is estimated at 12 per 1000 live births.[1] Significant advances in surgical management and decreases in mortality and morbidity have made functional outcome the primary focus of contemporary research. Follow-up studies have identified developmental and neurological abnormalities in as many as 25% of survivors. Neurological evaluation mostly revealed deficits in neurocognitive (language, attention) or motor functions (balance, hopping).[2] On developmental testing, children with CHD showed poorer hand-eye coordination and lower scores on locomotor functioning, personal/social, and speech and hearing scales than healthy control subjects.[3] Assessment of IQ in school-aged children with CHD showed scores within the expected range,[4,5] although lower than in the general population.[6] Neuropsychological assessment was mostly performed on isolated diagnostic groups and revealed problems on several cognitive functions.[7-16]

The purpose of the present study is to characterize the neuropsychological outcome of school-aged children with a surgically corrected cyanotic or acyanotic CHD and compare their performances with those of age- and sex-matched healthy controls. In contrast to most studies, enrollment of children was not limited to those with a specific diagnosis but covered the whole spectrum of CHD, to draw conclusions on the neuropsychological functioning of children with CHD in general and not to link specific neurocognitive profiles to specific diagnoses. We evaluated differences in neuropsychological outcome between cyanotic and acyanotic CHD.

METHODS

Patient Characteristics and Medical Data

Patients with various CHDs, operated in the Ghent University Hospital between 1995 and 1999, with a birth weight >2000 g, without perinatal problems, and without

CHD	Congenital heart disease	WISC-III	Wechsler Intelligence Scale for Children-3rd edition
NEPSY	A developmental NEuroPSYchological assessment		

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Submitted for publication Aug 22, 2006; last revision received Dec 21, 2006; accepted Feb 5, 2007.

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0022-3476/$ - see front matter

10.1016/j.jpeds.2007.02.020

noncardiac malformations or genetic abnormalities (Down syndrome, Velocardiofacial syndrome, and DiGeorge syndrome) were contacted and invited to participate in the study (n = 163). Several candidates had moved and could not be located (n = 17). Various reasons were given by nonparticipants: presence of a developmental disorder (n = 2; one boy with autism, one boy with a severe learning disorder), testing being too time consuming (n = 27), awaiting new cardiac surgery for the child (n = 2), not wanting to confront the child with something that happened a long time ago (n = 19), and stating that the child has no cognitive problems and participating would imply that he or she does (n = 8). Reasons for not participating remained unclear in 31 case patients who did not respond in any way to the invitation. All children with tetralogy of Fallot and all other children showing characteristic features of genetic abnormalities at birth had a genetic screening (fluorescence in situ hybridization, FISH) to exclude for DiGeorge/velocardiofacial syndrome. In total, 57 patients were included in the project, of which we selected only those patients who had undergone an open-heart procedure (n = 43; 21 girls, 22 boys). We compared the total CHD group with the healthy controls and the cyanotic CHD group (n = 26) with the acyanotic CHD group (n = 17). For each child in the patient group, a healthy sex-, age-, and educational-level matched control was included. The healthy children were contacted through their school boards. All parents gave written informed consent. At the time of testing, all children (ie, the total CHD group and healthy controls) attended school full-time, and according to their parents, they participated actively in sports and social activities. We calculated the Hollingshead Four Factor Index of Social Status to quantify the socioeconomic status of each family. This index uses education, occupation, sex, and marital status to determine a composite social status. The score was computed by multiplying the Occupation scale value by a weight of 5 and the Education scale by 3, and then summing these products. The raw scores range from 8 to 66, with higher scores reflecting higher socioeconomic status.[17] The local Ethical Committee approved the study. Procedures were in accordance with the recommendations found in the Helsinki Declaration of 1975.[18]

Medical data were collected from the patients' files. We included birth weight and length, and Apgar scores immediately after birth and after 10 minutes. All children had undergone an open-heart operation with full-flow cardiopulmonary bypass under moderate hypothermia (25°C-33°C).

Neuropsychological Assessment

After agreeing to participate, children were invited for a neuropsychological assessment of 2 to 3 hours duration. The child was tested with a short form of the Wechsler Intelligence Scale for Children-3rd edition, Dutch version (WISC-III NL). The short form included two verbal subtests (Information and Vocabulary) and two performance subtests (Picture Completion and Block Design).[19] A deviation IQ was calculated using the procedure suggested by Sattler.[20] On subtest level, a mean performance of 10 (SD = 3) is expected. Mean Estimated Full Scale IQ is 100 (SD = 15).

The neuropsychological battery consisted of all core subtests of the NEPSY (a developmental NEuroPSYchological assessment). The NEPSY tests the child's neuropsychological development in five functional domains to detect subtle deficiencies, within and across these functional domains, which can interfere with learning in preschool and school-aged children.[21] In the domain *Attention and Executive Functioning*, children had to perform three tasks. The subtest Tower measures nonverbal planning and problem solving. The subtest Auditory Attention and Response Set tests vigilance, sustained auditory attention, and the ability to shift and maintain new and complex sets. The subtest Visual Attention reports on speed and accuracy of selectively focusing and maintaining attention on a visual target. The domain *Memory* includes both verbal (Narrative Memory, Memory for Names) and visual memory tasks (Memory for Faces). The subtests Phonological Processing (phonemic awareness), Speeded Naming (access to and production of names of recurring colors, sizes, and shapes), and Comprehension of Instructions (ability to process and respond quickly to verbal instructions of increasing complexity) form the domain *Language*. *Visual-spatial Skills* were assessed by two subtests: Arrows (line orientation and directionality) and Design Copy (ability to copy two-dimensional geometric figures). Fingertip Tapping (finger dexterity and motor speed), Imitation of Hand/Finger Positions (ability to imitate hand/finger positions), and Visuomotor Precision (fine motor skills, hand-eye coordination) were the tasks to perform in the domain *Sensorimotor Functioning*. A mean performance on the domains is 100 (SD 15); on subtest level a mean performance of 10 (SD 3) is expected.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences for Windows (version 12.0) (SPSS, Chicago, Ill). Demographics (age at the moment of testing, sex, and educational level of both parents, Hollingshead Index), medical characteristics (birth weight, Apgar scores), and outcome measures (Estimated IQ, NEPSY) were compared between the total CHD group and the healthy control group. Nominal data were analyzed with χ^2 statistics. Normality was checked by Kolmogorov-Smirnov tests. If the data were not normally distributed, the nonparametric Wilcoxon's signed rank test was used. For normally distributed data, multivariate analyses of variance were used with group (total CHD group vs healthy control group, cyanotic CHD group vs acyanotic CHD group) as a between-subject factor; the WISC-III subtests, Estimated Full Scale IQ, NEPSY domains and subtests as dependent variables; and educational level of the father as covariate.

RESULTS

Patient Characteristics and Medical Data

The mean age at testing of the total CHD group was 8 years, 8 months ±1 year, 6 months. As a result of matching,