Visuospatial deficits in children 3 - 7 years old with shunted hydrocephalus

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Objective. To define non-verbal intelligence deficits in children 3 - 7 years of age following shunted hydrocephalus (HCP).

Design. Prospective randomised single-blinded study. Thirty shunted HCP (study) and 30 cardiac (control) patients between the ages of 3 and 7 years were compared on eight non-verbal subtests of the Junior South African Individual Scales (JSAIS).

Setting. Department of Neurosurgery at Wentworth Hospital, Durban, South Africa.

Results. Significant differences between the HCP and cardiac groups were recorded on all eight subtests of the JSAIS. The HCP group experienced problems with spatial orientation, perceptual planning and organisation, emotive deficits, abstract thinking and visual concepts.

Conclusion. All patients with shunted HCP had specific deficiencies in defined cognitive areas of non-verbal intelligence when compared with the controls. Futher studies are warranted to determine the effects of ventriculoperitoneal shunting on non-verbal intelligence so that the special educational needs of HCP children may be met.

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The condition of hydrocephalus (HCP) and its secondary sequelae have been well documented.[1,2] Previous reports have documented the impact of an enlarging ventricular system on the developing brain and neuropsychological consequences in HCP children.[1-4] Furthermore, most children with shunted HCP have been reported to demonstrate poorer non-verbal intelligence quotient (IQ) scores relative to verbal IQ scores.[1,2,4-6]

Donders *et al.* reported that HCP children have a relatively reduced efficiency in visuospatial skills.[2] This deficit may become more pronounced as children become older, with increased environmental demands placed on them. According to reports HCP is especially destructive of white matter tissue.[4] The relative inefficiency of HCP children for some visuospatial measures is a reflection of persistent dysfunction in the posterior regions of the right cerebral hemisphere where there is more white matter interregional integration. In addition, extracranial cerebrospinal fluid (CSF) diversionary procedures such as ventriculoperitoneal shunts are usually placed in the right parieto-occipital region and may further compound these visuospatial deficitis. The hypomyelination and thinning of the fragile frontal lobes in children with shunted HCP may also selectively impair non-verbal intelligence.[1]

The aim of the present study was to define the visuospatial deficits in shunted HCP children aged between 3 and 7 years. We selected this age group as we believe that early identification of problems in non-verbal intelligence will assist in planning for the special learning needs of this population group.

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Patients and methods

Subjects

Thirty children diagnosed with HCP were compared with 30 cardiac patients. The diagnosis of HCP (congenital or acquired) was made on the basis of clinical and computed tomography (CT) examinations. All patients in the HCP group were shunted in the first 6 months of life.

The patients were randomly selected from our outpatient clinics. They were controlled for age, sex, socio-economic status and surgery, with both groups of patients having undergone a surgical procedure recently. The rationale for comparison of the HCP group with the cardiac group was an attempt to control for the effects of surgery and hospitalisation. Only stable postoperative patients with the ability to use both hands and no clinical visual impairment were entered into the trial.

Procedure

Non-verbal subtests of the Junior South African Individual Scales (JSAIS)[7] were administered to both groups. The JSAIS is formulated along the lines of the Wechsler Test.[8] The child's intelligence is measured with the aid of a point scale in relation to the performance of a group of children more or less the same age. The JSAIS included the following battery of subtests:

The Form Board Test measures the cognitive processes of perceiving forms, together with the recognition of shapes and colour, the comprehension and manipulation of three-dimensional figural stimuli, comprehension of part-whole relationships, comprehension of position and arrangement of geometric visual figures in space, discrimination of forms, visual organisational ability and psychomotor dexterity.

The Block Design Test measures convergent production or reasoning through the use of figural material (hence visual-spatial reasoning). Specific cognitive processes described as comprehension of figural stimuli, pattern perception, pattern analysis, pattern recoding and pattern synthesis, abstract conceptualisation and the ability to generalise visual-motor co-ordination, visual-motor speed and perception of spatial relations are reported to underlie completion of this test.

The Absurdities A Test measures the ability to evaluate the correctness of figural information. It requires visual memory for objects and environmental details as well as the ability to discriminate visually.

The Absurdities B Test measures the ability to notice absurdities in visual material. It is intended to measure the evaluation of figural systems and figural implications, in contrast to the evaluation of figural information as in Absurdities A.

The Form Discrimination Test measures the ability to distinguish differences and similarities between complex units of figural information. Form discrimination is a complex task requiring visual reasoning ability together with perception of form, spatial orientation, perceptual constancy and perceptual organisation.

The Gestalt Test measures the ability to perceive apparently disorganised or unrelated parts as a meaningful whole within a time limit. Essential elements of the test performance include visual alertness, visual memory and artistic aptitude.

The Picture Puzzle Test measures visual concept formation. It is presumed that form perception, spatial orientation and visual-perceptual co-ordination are essential elements of test performance.

The Copying Test measures the ability to reproduce a visually presented design correctly. The specific skills involved include hand-eye co-ordination, perceptual ability and visual-motor organisational ability.

Statistical analysis

T-test statistical analysis was performed between the means in the study and control groups, on the 8 non-verbal subtests of the JSAIS. Differences were considered significant at $p < 0.05$. Comparison with norms was not performed in this study as norms reflected in the JSAIS manual involved the conversion of raw scores into age groups. The analysis in this study was based on groups and not individuals.

Results

Twenty-one of 30 patients (70%) had congenital HCP: 4 patients had aqueduct stenosis, 9 had communicating HCP, 5 had Dandy-Walker malformation (DWM), 1 had Chiari malformation, and 2 had arachnoid cysts. The remaining 9 patients had acquired HCP: tuberculous HCP (4), post-traumatic HCP (2), and post-meningitic HCP (3).

All patients with tuberculous meningitis and HCP were classified as grade 1 (patient with a normal sensorium and no neurological deficit).[9] No evidence of vascular insults was detected on neuroimaging.

The following motor deficits were recorded on study entry. In the congenital group, 5 children could not walk (aqueductal stenosis 3, DWM 1, congenital communicating HCP 1), while 3 children could not stand (aqueductal stenosis 1, DWM 1, and congenital HCP 1). A single patient with acquired HCP following a focal traumatic brain injury had a right-sided monoparesis. However, owing to small numbers of patients in each subgroup, no meaningful analysis of aetiology was performed.

Statistical significance was found between the mean scores for the study and control groups for all 8 subtests of the JSAIS. *T*-test analysis showed significant differences on the Form Board Test, Block Design Test, Absurdities A Test, Absurdities B Test, Gestalt Test and Copying Test ($p < 0.001$) and for the Form Discrimination Test and Picture Puzzles Test ($p < 0.01$). The standard deviations (SDs) for most of the subtests were found to be very high, indicating a high variability in scores.

Similar mean scores for the 2 HCP groups across the 8 subtests of the JSAIS were recorded. It was not possible to determine whether there was any significance between these mean scores as there was a large variance in the number of subjects in the groups. Similar mean scores were obtained on 4 subtests of the JSAIS for shunt insertion on the left and right side of the brain. However, there were too few subjects (10%)

Table I. Summary of demographic and medical information for the study and control groups

Variable	Study group	Control group
Mean age in months	57.6	62.4
Sex distribution (M : F)	16 : 14	13 : 17
Family income (*N*)		
< R100	15	15
R100 - 1 000	12	13
> R1 000	3	2
Patients receiving medication (*N*)	8	18
Patients not receiving medication (*N*)	22	12

Table II. Summary of results for the study (HCP, $N = 30$) and control (cardiac, $N = 30$) groups on the eight subtests of the JSAIS

Sub-tests of the JSAIS	Mean study score	SD	Mean control score	SD	T-test	*p*-Value*
Form Board	3.866	3.674	8.500	4.141	-4.584	0.001
Block Design	8.566	8.435	19.566	12.378	-4.022	0.001
Absurdities A	3.833	4.518	7.933	4.645	-3.465	0.001
Absurdities B	.366	.889	3.566	2.750	-6.063	0.001
Picture Puzzles	2.566	2.885	5.033	3.056	-3.214	0.002
Gestalt	1.566	1.381	5.333	5.491	-3.643	0.001
Copying	1.100	1.748	5.533	6.317	-3.704	0.001
Form Discrimination	4.833	4.800	8.866	6.781	-2.659	0.01

**t*- test

with shunts inserted on the left side to ascertain any conclusive findings. Table I illustrates the demographic distribution, family income level and medication record of the study and control cohorts. Chi-squared analysis did not reveal a significant relationship between the two groups, except for current medication ($\chi^2 = 6.787$, df =1, $p < 0.05$). Table II illustrates that the study group's performance on each of the 8 subtests of the JSAIS was considerably worse than that of the cardiac group ($p < 0.001$).

Discussion

The neuropsychological sequelae of HCP and the possible benefits of shunt insertion for later cognitive and emotional development of the child have been inadequately studied. The present study reports on the neuropsychological test performances of children between 3 and 7 years of age who were shunted for HCP in the first 6 months of life.

The presence of different types of HCP with varying levels of CSF obstruction may have influenced the poorer performance of the HCP group. However, Riva *et al.*[10] reported on patients with different types of HCP, including subjects with aqueductal stenosis shunted early, aqueductal stenosis shunted late, HCP secondary to major supratentorial malformations, and Chiari malformations. Correlative analysis revealed that variables such as post-surgical haematomas or hygromas and the number of shunt revisions did not correlate with impaired IQ scores, nor did 'site of obstruction' of the HCP which would ultimately determine the type of HCP. These authors also noted that only lesions located in the hemispheres changed neuropsychological functions, while malformations in the posterior fossa did not interfere with visual-perceptual intelligence.[11]

Dennis *et al.*[1] also studied HCP children with different aetiologies and found no significant difference between the different types of HCP on any IQ measurement. The latter study included HCP secondary to Chiari malformations, encephalocele, aqueduct stenosis, DWM, intraventricular haemorrhage, haematoma, infections, subdural hygroma and arachnoid cysts. They concluded that the type of HCP does not affect the level or the pattern of intelligence. However, IQ scores may be misleading and cognitive tests need to be analysed independently.[12] The broad spectrum of HCP subjects studied in the literature makes it difficult to draw conclusive findings on diagnosis and non-verbal measures.

Non-verbal intelligence as measured by the JSAIS comprises various cognitive components including visuo-perception, visual-construction, form discrimination, visual memory, visual object and shape recognition, visual motor-organisational ability and visual closure. The lower mean scores of the HCP group compared with the cardiac group on all 8 subtests of the JSAIS suggest specific deficiencies in defined cognitive areas of non-verbal intelligence in this group.

T-test analyses recorded a significant difference in performance between the HCP and cardiac groups for all subtests of the JSAIS (Table II). HCP children may therefore experience defects with spatial orientation, i.e. their ability to relate the position, direction or movement of objects in space.[12] The right hemisphere is reported to be superior to the left in fitting designs into larger matrices, in sorting shapes into categories, in perceiving wholes from a collection of parts and in the intuitive perception of geometric principles.[13]

Perceptual organisational difficulties in the HCP group may have contributed to their lower mean scores on the Block Design Test. Block Design scores tend to be lower with other forms of brain insult too. Furthermore, Block Design deficits associated with lateralised lesions are usually most common and most pronounced when the lesions involve the posterior, particularly parietal areas on the right side.[12] It is therefore possible that the hydrocephalic group's poorer performance on the Form Board Test may be due to a possible lesion in the right cerebral hemisphere, consistent with the side of shunt insertion in 24 of 30 patients (80%). However, the mean scores of patients with shunt insertion to the left and right hemispheres are not possible due to inadequate sample sizes.

However, Lezak *et al.*[12] reported that constructional disorders reflected the involvement of both hemispheres in processing spatial information. Left-sided lesions are apt to disrupt the programming or ordering of movements necessary for constructional activity, while diagonality in design or construction reflects right hemisphere lesions. Visuo-spatial defects are therefore described as being associated with impaired understanding of spatial relationships or defective spatial imagery. In the present study, the HCP group were able to use their hands to rotate and manipulate the blocks, but were not able to organise the blocks according to the pattern within the given timeframe. Extending the time limits of testing may yield more conclusive data.

To perform the task of identifying missing details in pictures, subjects have to rely on long-term (semantic) memory, together with the use of visual organisation and reasoning abilities.[12] The prefrontal lobes play a critical role in long-term memory, especially when learning materials are complex and require semantic processing during the encoding stage.[14] It is further speculated that HCP has damaging sequelae on the development of the prefrontal lobes that are particularly concerned with executive functions, mental flexibility and conceptual planning abilities.[5]

Difficulties in identifying what is humorous (as in the Absurdities B Test) could be related to socioemotive deficits, specifically in HCP children. In support of this assumption, Hilgard *et al.*[15] suggested that some forms of emotional expression appear to be inborn, while others develop through maturation. However, the interaction between experience and the environment is regarded as important in modifying emotional expression. The right hemisphere predominantly processes information with emotional content.[16] We are unsure at present if the location and side of shunt insertion could have produced the lower scores on the Absurdities B Test and the other subtests of the JSAIS; however, the critical placement of the shunt catheter in the right parieto-occipital region is worrisome and cannot be excluded from the present results as the cause of the recorded deficits.

The Picture Puzzle Test and Gestalt Test require conceptual reorganisation of disarranged pieces into a whole picture. It therefore requires abstract thinking and the ability to form visual concepts quickly and translate them into rapid hand responses.[12] It is therefore a test of the speed of visual-motor organisation. The speed component of this test renders it relatively vulnerable to brain insults, especially with right posterior lesions.[12]

Copying tasks require a high level of integrative behaviour, i.e. hand-to-eye co-ordination, visual-motor organisational ability and the perception of detail. In the present study, the HCP group could manoeuvre their pencils, but had great difficulty in integrating or organising parts of the pattern into a whole. Difficulty in drawing the patterns correctly suggests deficits in visual and motor integration and the processing of information perceived. This discrepancy in non-verbal processing in HCP children may therefore be attributed to an impaired understanding of spatial relationships rather than constructional difficulties. The poor performance scores of HCP children in the present study on the Form Discrimination Test may be due to both the complexity of the task and to an information-processing deficit.[14] It is possible that HCP patients experienced difficulty integrating and processing complex information as they were unable to respond correctly to drawings that were displaced, rotated or distorted. There is further need to study these specific perceptual difficulties.

Conclusion

The present study attempted to define the visuospatial deficits in children aged 3 - 7 years with shunted HCP, by exploring specific measures of non-verbal skills. The insertion of the shunt catheter in the right parieto-occipital region may have influenced the visuospatial deficits present in the study group.We recommend that future studies should take into account the side and site of shunt insertion.

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