MEASURING RIGHT-HEMISPHERE DYSFUNCTION IN CHILDREN: VALIDITY OF TWO NEW COMPUTER TESTS

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Visuospatial, attentional and emotional disorders following right-hemisphere injuries in adults have been studied in detail (Benton 1969; Botez and Olivier 1985; De Renzi 1985; Heilman *et al.* 1985, 1986), but the neuropsychological consequences of acquired lesions of the right hemisphere in children have received far less attention. Denckla (1978) found that children with left-sided neurological signs failed to make normal relationships with their peers. Ferro *et al.* (1984) described visuospatial neglect in three children with right-hemisphere lesions. Riva and Cazzaniga (1986) studied 48 children with unilateral lesions acquired early in life, and found that the mean WISC-R Performance IQ of the 26 children with right-hemisphere lesions was significantly lower than that of the children with left-sided lesions.

Voeller (1986) defined 'right-hemisphere deficit syndrome' as left-sided neurological signs, higher Verbal than Performance IQ (WISC-R), and better scores for reading and spelling tasks than for one involving calculation. All 15 of the children she studied also had an attention deficit disorder. Seven were unable to interpret facial affective cues, while others could not express their own feelings but appeared to be sensitive to and aware of the emotions of others. Njiokiktjien (1987) made similar observations in his study of 20 four- to 15-year-old children with acquired left-sided hemiparesis. In children with early lesions, however, Boll and Barth (1981) observed that differences between WISC Verbal and Performance IQs did not provide valid means of lateralizing brain damage to either the left or right hemisphere, but that a deficient Performance IQ was more a characteristic of diffuse brain damage.

The Line Orientation Test (LOT) and the Facial Recognition Test (FRT), developed by Benton and co-workers, are considered to be valid diagnostic tools for measuring right-hemisphere dysfunction in adults (Benton and van Allen 1968; Benton *et al.* 1978, 1983). These authors obtained a predictive value of 85 per cent for the LOT and 83 per cent for the FRT. In children, however, such a direct correlation could not be confirmed (Paquier *et al.* 1992). That is why it was necessary to develop a valid diagnostic tool to assess the visuospatial skills of children with known or suspected disease of the right hemisphere.

Our aim was to create a test to measure right-hemisphere function with the same validity as the LOT and FRT in adults. We wanted the tests to be appealing and easy to use. For this reason two computer-mediated tests were developed, the Right-hemisphere Dysfunction Test (RHDT) by L.B. and the Visual Perception Test (VPT) by P.vdW.

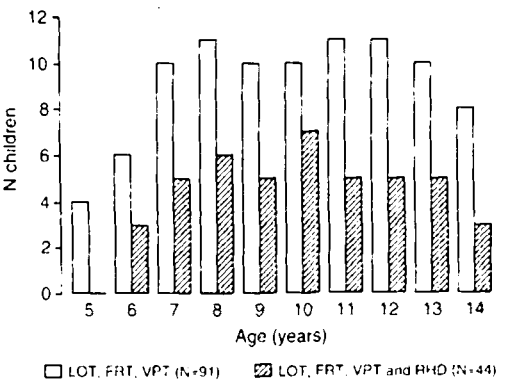

Fig. 1. Age distribution of normal comparison children.

Normative data of the LOT and FRT were gathered from children, and the RHDT and VPT from children and young adults. The normative data of the LOT and FRT were compared with those published earlier (Benton *et al.* 1983, Paquier *et al.* 1992). Sensitivity, specificity, predictive value and accuracy of all four tests were determined in a group of children with acquired lesions of the right or left cerebral hemisphere.

Material and method

Right Hemisphere Dysfunction Test (RHDT)

This test is a computer-mediated variant of a classic 'bisect-a-line' visuospatial test. Patients with a right-hemisphere lesion ignore the hemispace contralateral to that lesion. When they are asked to bisect a line, they place their division mark to the right of the midline. In order to create the test, we adapted the visual matching unit of the VISPA (Visuospatial Cognitive Training System, Dekro Inc., Atlanta, GA). In the upper part of the blue screen, there is a yellow line bisected by a yellow demarcation. In the lower part of the screen, one identical bisected line is shown, together with two almost identical bisected lines. The identical line is positioned randomly in the left, middle or right position in the lower part of the screen, and should be touched with a light pen (PXL-350 HI-RES light pen, FTG Data Systems, Stanton, CA). The length of the lines and the position of the demarcations may vary. A total number of 120 trials is presented, divided in two series of 60, with a pause between the series. The test procedure takes approximately 15 minutes. The total number of errors and the average search time are recorded and shown by the computer.

Visual Perception Test (VPT)

Howes and Boller (1975) demonstrated that patients with right-hemisphere lesions had increased reaction times of the ipsilateral hand on stimulation of the left hemifield, compared with patients with left-hemisphere lesions on stimulation of the right hemifield. This observation was confirmed by Heilman and van den Abell (1979), in a study of normal adults. They showed that reaction times of the right hand were reduced by warning stimuli projected to the right hemisphere more than by warning stimuli projected to the left hemisphere. The VPT was developed with these observations in mind. The child is asked to concentrate on a 5mm wide white fixation line in the middle of a dark computer screen. A small, white, star-shaped stimulus appears at random at one of the 17 positions on the screen. The child is asked to get rid of the white star as quickly as possible by pushing the space bar. After a variable interval, the stimulus reappears at another position on the screen. The stimulus reappears 10 times at any of the 17 positions distributed equally over the screen. The test takes about 15 minutes. The mean response latency is calculated for each position, and the shortest is selected. Mean reaction times in the left and right hemifields are calculated from the most peripheral positions on the left and right sides.

Subjects

NORMAL SUBJECTS

Normative data for the LOT, FRT, RHDT and VPT were drawn from a group of 91 children (52 boys and 39 girls) admitted to the University Hospital Rotterdam for minor non-neurosurgical procedures. They were assessed on one of the last days of their stay in hospital, or during their first follow-up visit to the outpatient clinic. All were aged between five and 14 years, were right-handed (as assessed by a standard questionnaire) and were attending a normal elementary school. They had

TABLE I
Mean scores on the LOT, FRT, RHDT and VPT

Age (yrs)	LOT	FRT	RHDT	VPT-srt[1]	VPT-L[2]	VPT-R[3]
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
5	14·8 (1·8)	30·5 (4·8)	—	553·1 (190·9)	847·2 (184·4)	725·0 (209·1)
6	19·2 (4·6)	32·3 (2·5)	17 (10)	396·6 (65·3)	494·3 (100·0)	558·5 (169·9)
7	19·0 (2·1)	35·9 (3·9)	14 (5)	325·8 (65·4)	405·6 (76·2)	443·1 (132·6)
8	19·4 (5·3)	39·0 (3·3)	14 (5)	303·4 (36·9)	377·5 (57·6)	381·8 (43·8)
9	21·3 (5·3)	40·8 (4·3)	10 (3)	285·4 (27·7)	344·6 (34·0)	363·0 (63·4)
10	23·3 (4·9)	42·5 (5·3)	7 (3)	255·2 (37·7)	315·0 (60·9)	318·7 (61·1)
11	22·5 (4·7)	42·0 (2·6)	7 (7)	254·3 (25·8)	291·7 (31·6)	300·1 (32·4)
12	24·4 (4·1)	44·5 (2·7)	6 (2)	229·0 (28·3)	284·8 (51·3)	271·9 (37·7)
13	23·6 (2·8)	43·5 (4·4)	9 (2)	243·2 (29·3)	287·6 (56·9)	301·2 (53·8)
14	21·6 (5·1)	41·8 (4·3)	10 (4)	238·1 (28·3)	293·4 (59·7)	281·6 (42·1)
19·3*	—	—	7 (3)	230·7 (39·9)	271·2 (50·2)	264·0 (46·5)

[1]VPT-srt = mean shortest reaction time (ms). [2]VPT-L = mean scores for left hemifield (ms). [3]VPT-R = mean scores for right hemifield (ms).
*Young adults: mean age 19·3 (SD 4·3) years.

normal visual acuity, no colour-blindness (Ishihara 1981), intact visual fields, normal eye-movements, no recognised neurological disorder, and had sustained no cerebral concussion in the preceding two years. They were not under sedative medication. Informed consent of parents and children was obtained.

All children completed the LOT, FRT and VPT. 44 of them (22 boys and 22 girls) also completed the RHDT. Their age distribution is shown in Figure 1. 14 normal young adults (eight males and six females, mean age 19·3 (SD 4·3) years) also completed the RHDT and VPT.

PATIENTS

We assessed 14 children (eight boys and six girls) with an acquired right- (nine cases) or left-sided (five cases) cerebral hemisphere lesion. In all cases, CT and/or MRI scans confirmed that lesions were limited to either the left or right hemisphere. An arteriovenous malformation was present in six patients (cases R2, R4, R8, L1, L2 and L4). Four of these (R2, R4, R8 and L4) had presented with an acute haemorrhage. In one patient (R6) the lesion was due to occlusion of part of the middle cerebral artery. Six patients suffered from a cerebral tumour (R1, R3, R5, R7, L3 and L5). In patients R3, R5, R7, L3 and L5, the tumour had been resected by the time of testing. Patient R9 had a large arachnoid cyst in the middle cranial fossa with substantial compression of the temporal lobe. All patients were in a stable clinical condition. In cases of surgery or acute onset of symptoms due to haemorrhage or infarction, testing was delayed for at least three months after the event. Due to various technical reasons, the VPT results of patients R5, R6 and L3 are not complete.

Statistical analysis

Following Benton *et al.* (1983), a score within the limits of one standard deviation was chosen as the normal range for all tests. The sensitivity of each test was calculated as the proportion of patients with insufficient test results within the group of patients with lesions of the right hemisphere. Specificity was calculated as the proportion of patients with normal test results in the group of patients with lesions of the left hemisphere. The predictive value of the tests was calculated as the proportion of patients with insufficient test results with a right-hemisphere lesion. Accuracy was calculated as the number of patients with a right-hemisphere lesion who had an abnormal score on this test, plus the number of patients with a left-hemisphere lesion with a normal score on this test, divided by the total number of patients with a right- or a left-hemisphere lesion.

TABLE II
Individual test performances of patients with a lesion of right or left cerebral hemisphere

Patient[1]	*Age (yrs)*	*Sex*	*Aetiology*	*LOT*	*FRT*	*RHDT*	*VPT (ms)*[2]		
							Srt	*L*	*R*
R1	7	F	Tumour	9*	40	26*	776*	603*	544
R2	9	M	Vascular	19	38	32*	397*	485*	439*
R3	12	F	Tumour	20	40*	20*	218	389*	279
R4	13	M	Vascular	18*	37*	21*	314*	407*	357*
R5	8	F	Tumour	18	33*	14	306	—	—
R6	11	M	Vascular	22	39	21*	343*	—	—
R7	8	M	Tumour	26	40	3	417*	583*	451*
R8	15	F	Vascular	20	44	9	282*	313	331*
R9	14	M	Arachnoid cyst	26	47	6	500*	627*	651*
L1	10	M	Vascular	17*	32*	3	289	477*	493*
L2	12	M	Vascular	14*	49	21*	240	264	265
L3	14	F	Tumour	17	32*	15*	—	—	—
L4	15	F	Vascular	21	46	12	233	255	341*
L5	6	M	Tumour	8*	34	16	627*	786*	757*

[1]R = right-hemisphere lesion; L = left-hemisphere lesion. [2]See Table I for definitions.
*Beyond standard deviation.

TABLE III
Comparison of all tests

	Sensitivity (%)	*Specificity (%)*	*Predictive value (%)*	*Accuracy (%)*
LOT	22	40	40	29
FTR	33	60	60	43
RHDT	56	60	71	57
VPT (shortest reaction time)	78	75	88	77
RHDT and VPT	89	40	72	71

Results

The test scores for the LOT, FRT, RHDT and VPT in normal children are shown in Table I. For the LOT, the correlations with the reference scores of the normal schoolchildren of Benton *et al.* (1983) and Paquier *et al.* (1992) were 0·73 and 0·81, respectively. For the FRT these correlations were 0·87 and 0·96, respectively. Thus we conclude that our research population may be compared with a normal school population. The data demonstrate that performance improves with age on all four tests. On the LOT, FRT and RHDT, normal adult scores are reached by the age of 10 years. On the VPT, adult scores are reached by the age of 12 years.

The individual test performances of the nine children with right-hemisphere lesions and the five children with left-hemisphere lesions are listed in Table II. On the LOT, two patients with a right-hemisphere lesion and three patients with a left-hemisphere lesion scored outside the normal range, which for this test is less than one standard deviation of the average score for age. On the FRT, three patients with a right-hemisphere lesion and two patients with a left-hemisphere lesion failed to obtain a normal score, which for this test is less than one standard deviation of the average score for age. On the RHDT, five patients with a right-hemisphere lesion and two patients with a left-hemisphere lesion performed outside the normal range, which is more than one standard deviation of the average score for age. On the VPT, seven patients with a right-hemisphere lesion and one patient with a left-hemisphere lesion performed outside the normal range, which is more than one standard

deviation of the average score for age.

Data concerning sensitivity, specificity, predictive value and accuracy calculated from these results are shown in Table III. They demonstrate that the sensitivity, specificity and accuracy of the RHD and VPT for detecting right-cerebral dysfunction in children are superior to the LOT and FRT, and that their predictive value is equal to those of the LOT and FRT in adults. The accuracy of predicting right-hemisphere dysfunction did not improve when performances of patients on the RHD and VPT were combined (Table III).

Discussion

The role of the right hemisphere in processing visuospatial information is firmly established in adults, and a great variety of tests and procedures have been devised to assess different aspects of spatial 'thinking' (Benton 1969; Botez and Olivier 1985; De Renzi 1985; Heilman *et al.* 1985, 1986).

The present results demonstrate that normative data of visuospatial tests derived from adults should not be used for children. If the adult standard norms in the LOT and FRT are used for normal children below the age of 10 or 11 years, they may incorrectly be considered impaired. Developmental studies indicate that around the age of 10 or 11 years, performance on visuospatial-oriented tests equals adult norms (Meerwaldt and Schmitz 1988). Our results suggest a similar developmental pattern, which was more prominent on the RHDT and VPT than on the LOT and FRT.

Paquier *et al.* (1992) used the LOT and FRT to study the performances of 18 children with left- and 15 children with right-hemisphere lesions. They concluded that poor performance on the LOT is not significantly associated with lesions of the right hemisphere. There was a moderately significant association between lesions of the right hemisphere and performance on the FRT. Our results with the LOT and FRT support their findings.

The LOT and FRT measure spatial perception at a fairly complex level. The LOT is based on the concept that the right hemisphere plays an important role in distinguishing line direction (Benton *et al.* 1983). The FRT was developed with the knowledge that prosopagnosia occurs almost exclusively as a result of dysfunction of the right hemisphere (Benton *et al.* 1983). To solve these complex tasks, children may draw on other strategies, not dependent on the right hemisphere (De Renzi *et al.* 1971, Meerwaldt 1982). Both the RHDT and VPT have a more basic design (*i.e.* correct estimation of a division of a line and optic localization of a stimulus, respectively), which would make them as pure a measure of one aspect of spatial thinking as could be conceived. The relatively high accuracy with which they detected right-hemisphere dysfunction supports this concept.

When studying the reaction times in the left and right hemifield on the VPT, we did not observe the significant differences described by Heilman and van den Abell (1979). This may be caused by the fact that subjects do not fix their eyes consistently on the central bar. The computer screen is relatively small and due to small eye-movements may not be observed by the same part of the visual cortex during the length of the test procedure.

We conclude that the VPT and RHDT are useful, valid and non-invasive tools to evaluate right-hemisphere function and to detect acquired visuospatial deficits in children. The tests are attractive for both patients and doctors, because the test programme is pleasant and easy to work with. It can be used as a bedside test or in the outpatient department.

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Authors' Apppointments

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SUMMARY
The validity of two new computer-mediated tests for the detection of right-cerebral hemisphere lesions in children—the Right-hemisphere Dysfunction Test and the Visual Perception Test—was evaluated. Normative data were drawn from a group of 91 children (aged five to 14 years) and 14 young adults. The tests were also administered to 14 children with acquired lesions of either right- or left-cerebral hemisphere. The results demonstrate that the Right-hemisphere Dysfunction Test and the Visual Perception Test, with predictive values of 71 per cent and 88 per cent, respectively, are useful in clinical practice for detection of right-hemisphere dysfunction in children.

RÉSUMÉ
Evaluation d'une dysfonction de l'hémisphère droit chez l'enfant: validité de deux nouveaux tests présentés par ordinateur
La validité de deux nouveaux tests présentés par ordinateur, pour la détection de lésions de l'hémisphère droit chez l'enfant, le test de dysfonction de l'hémisphère droit et le test de perception visuelle, a été évaluée. Les données de référence ont été obtenues sur un groupe de 91 enfants (âgés de cinq à 14 ans) et 14 jeunes adultes. Les tests furent également présentés à 14 enfants porteurs de lésions acquises de l'hémisphère droit ou gauche. Les résultats ont montré que le test de dysfonction de l'hémisphère droit et le test de perception visuelle, avec une valeur prédictive respective de 71 pour cent et de 88 pour cent, sont utiles en pratique clinique pour détecter une dysfonction de l'hémisphère droit chez l'enfant.

ZUSAMMENFASSUNG
Beurteilung einer Dysfunktion der rechten Hemisphäre bei Kindern: Validität von zwei Computertests
Es wurde die Validität von zwei neuen Computertests zur Erkennung von Läsionen der rechten Hirnhemisphäre bei Kindern untersucht—Dysfunktionstest der rechten Hirnhemisphäre und visueller Perzeptionstest. Normale Daten wurden von einer Gruppe von 91 Kindern (fünf bis 14 Jahre alt) und 14 jungen Erwachsenen erhoben. Außerdem wurden 14 Kinder mit erworbenen Läsionen der rechten oder linken Hirnhemisphäre mit diesen Tests untersucht. Die Ergebnisse zeigen, daß der Dysfunktionstest der rechten Hemisphäre und der visuelle Perzeptionstest mit prognostischen Ausagewerten von 71 bzw. 88 Prozent für die klinische Anwendung zur Diagnostik einer Dysfunktion der rechten Hemisphäre bei Kindern geeignet sind.

RESUMEN
Medición de la disfunción del hemisferio derecho en niños. Validez de un nuevo tests computarizado
Se evaluó la validez de dos nuevos tests computarizados para la detección de lesiones del hemisferio cerebral derecho en niños (test de disfunción del hemisferio derecho y test de percepción visual). Los datos normativos se extrajeron de un grupo de 91 niños (de cinco a 14 años) y 14 adultos jóvenes. Los tests se pasaron también a 14 niños con lesiones adquiridas de hemisferio derecho o izquierdo. Los resultados demostraron que el test disfunción del hemisferio derecho y el de percepción visual, con valores predictivos del 71 y el 88 por ciento repectivamente, son útiles en la practica privada para la detección de la disfunción del hemisferio derecho en niños.

References

Benton, A. L. (1969) 'Disorders of spatial orientation.' *In* Vinken, P. J., Bruyn, G. W. (Eds.) *Handbook of Clinical Neurology, Vol. 3: Disorders of Higher Nervous Activity.* Amsterdam: Elsevier.

— van Allen, M. W. (1968) 'Impairment in facial recognition in patients with cerebral disease.' *Cortex,* **4,** 344–358.

— Varney, N. R., de Hamsher, K. S. (1978) 'Visuospatial judgement. A clinical test.' *Archives of Neurology,* **35,** 364–367.

— de Hamsher, K. S., Varney, N. R., Spreen, O. (1983) *Contribution to Neuropsychological Assessment.* Oxford: Oxford University Press.

Boll, T. J., Barth, J. T. (1981) 'Neuropsychology of brain damage in children.' *In* Filskov, S. B., Boll, T. J. (Eds.) *Handbook of Clinical Neuropsychology.* New York: John Wiley & Sons.

Botez, M. I., Olivier, M. (1985) 'Parietal lobe syndromes.' *In* Vinken, P. J., Bruyn, G. W. (Eds.) *Handbook of Clinical Neurology, Vol. 45: Clinical Neuropsychology.* Amsterdam: Elsevier.

Denckla, M. B. (1978) 'Minimal brain dysfunction.' *In* Chall, J., Mirsky, A. (Eds.) *Education and the Brain.* Chicago: Chicago University Press.

De Renzi, E. (1985) 'Disorders of spatial orientation.' *In* Vinken, P. J., Bruyn, G. W. (Eds.) *Handbook of Clinical Neurology, Vol. 45: Clinical Neuropsychology.* Amsterdam: Elsevier.

— Faglioni, P., Scotti, G. (1971) 'Judgement of spatial orientation in patients with focal brain damage.' *Journal of Neurology, Neurosurgery and Psychiatry,* **34,** 489–495.

Ferro, J. M., Martins, I. P., Tavora, L. (1984) 'Neglect in children.' *Annals of Neurology,* **15,** 281–284.

Heilman, K. M., van den Abell, T. (1979) 'Right-hemisphere dominance for mediating cerebral activation.' *Neuropsychologia,* **17,** 315–321.

— Valenstein, E., Watson, R. T. (1985) 'The neglect syndrome.' *In* Vinken, P. J., Bruyn, G. W. (Eds.) *Handbook of Clinical Neurology, Vol. 45: Clinical Neuropsychology.* Amsterdam: Elsevier.

— Bowers, D., Valenstein, E., Watson, R. T. (1986) 'The right hemisphere: neuropsychological functions.' *Journal of Neurosurgery,* **64,** 693–704.

Howes, D., Boller, F. (1975) 'Simple reaction time: evidence for local impairment from lesions of the right hemisphere.' *Brain,* **98,** 317–332.

Ishihara, S. (1981) *Ishihara's Design Charts for Colour Blindness of Unlettered Persons.* Tokyo: Kanehara.

Meerwaldt, J. D. (1982) *The Rod Orientation Test in patients with right-hemisphere infarction.* (Thesis.) Alblasserdam: Decor Davids.

— Schmitz, P. I. M. (1988) 'Development of visual and tactile rod orientation in children.' *Behavioural Brain Research*, **30**, 145–149.
Njiokiktjien, C. (1987) *Pediatric Behavioural Neurology*. Amsterdam: Suyi.
Paquier, Ph., van Mourik, M., van Dongen, H. R., Catsman-Berrevoets, C. E. (1992) 'The clinical value of the line orientation and facial recognition test in children with acquired unilateral cerebral lesions.' *Journal of Clinical Experimental Neuropsychology*, **14**, 400. (*Abstract.*)
Riva, D., Cazzaniga, L. (1986) 'Late effects of unilateral brain lesions sustained before and after age one.' *Neuropsychologia*, **24**, 423–428.
Voeller, K. K. S. (1986) 'Right-hemisphere deficit syndrome in children.' *American Journal of Psychiatry*, **143**, 1004–1009.