Validation of a simple screening test for elementary visuo-spatial perception deficit

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Title:

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3 Figures and 2 Tables

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Abstract

AIM :

Reliability and validity of a screening test for a deficit in elementary visuo-spatial perception (EVSP) are evaluated.

METHOD :

This prospective study collected performance from 210 typically-developing individuals and evaluated the internal consistency of the EVSP screening test. Test-retest reliability was examined on 25 individuals. Validity also involved retrospective clinical data collected from 223 non-typically developing children coming to the hospital for out-patient consultation.

Since EVSP matures through childhood, we standardized the EVSP screening test scores by age category and performed Pearson correlations with standardized clinical tests scores.

RESULTS:

Test-retest reliability (intraclass correlation coefficient =.76) and internal consistency (Cronbach's alpha = .76) were satisfactory.

Construct validity included correlation with the subtests of the WISC-IV involving visuo-spatial analysis (Matrix Reasoning and Block Design: $p<0.01$, Symbol Search and Coding: $p<0.05$) and was reinforced by the expected non-correlation between the Verbal Comprehension Index and EVSP.

EVSP correlated with Manual dexterity of the M-ABC ($p<0.05$) and the Working Memory Index ($p<0.05$) of the WISC-IV including the subtest Arithmetic ($p<0.01$).

INTERPRETATION:

This screening test is reliable and valid to evaluate EVSP before more complex cognitive or motor assessment.

INTRODUCTION:

Visual information arrives in the primary visual area, entry point to the cortical level, and is then distributed towards other more specialized visual areas for further processing. There is evidence of a global organization of these specialized areas according to two anatomical pathways. One occipito-temporal pathway, called the visual ventral stream, is essentially specialized in the analysis of the intrinsic properties of visual objects (shapes, color, texture...) to identify them: « What » function. Another one, the occipito-parietal pathway, called the visual dorsal stream, is dedicated to the processing of the spatial properties of objects (their relative position, size, length, angle…): « Where » function [1-4]. We will call this « Where » function elementary visuo-spatial perception (EVSP) because it is an elementary function contributing to the development of other cognitive and visuo-motor functions. However, it is not a primary function as it relies on spatial working memory processes[5]: analyzing the relative positions or the extent of stimuli over a large spatial scale requires different "snapshots", collected through ocular (overt) or attentional (covert) exploration, and integrated to create an accurate visual representation. Indeed, visual projections do not lead to an isomorphism between the external space and the space represented in the primary visual cortex: what is seen in central vision is largely over-represented on the cortical surface to the detriment of peripheral vision (central magnification). Only areas of the dorsal visual stream appear able to compensate actively for this deformation of visual representation in primary visual cortex and provide an accurate spatial representation of the visual scene, also useful to guide actions toward the environment[6].

The literature has raised deficits of EVSP in Developmental Coordination Disorder[7-9] and in Specific Learning Disorder (SLD), especially in dyslexia[10-12] and dyscalculia[12-15]. It is also classically suspected as impaired in children with premature birth and impaired binocular vision[16]. Because EVSP is usually evaluated in clinical routine using multiple, complex and non-specific tests, we designed a simple screening test aimed at testing EVSP in isolation, i.e. without involving any complex language, praxis, and visual gnosia. It was built based on subtests from pre-existing batteries and adapted to broaden the range of difficulty and increase sensitivity[1]. The material and the instructions were made as clear and simple as possible. The material consisted of simple meaningless geometrical shapes with pairs of stimuli to compare, each pair presented in isolation on a different sheet. The entire test comprised six subtests and precise comparison instructions were given for each subtest, accompanied by clear examples. It is simple to administer to children as early as 4 years old and lasts maximum 15 minutes. This fast and easy test could be useful in order to exclude or detect an EVSP deficit before any complex cognitive or motor assessment.

Starting the validation of this screening test, we collected data from typically developing children from 4 to 12 years old and adults, as well as from two stroke patients who presented with a bilateral lesion of the dorsal stream in adulthood and performed significantly lower than the adults' group[1]. We could therefore establish that EVSP as evaluated with our screening test is a developing process that approaches typical adult level only around 12 years of age and anatomically involves the dorsal visual stream.

In the present study, we studied the psychometric properties of our screening test to evaluate its usefulness to assess a clinical population of non-typically developing individuals: score distribution, internal consistency and test-retest reliability. To this aim, we increased the sample of typically developing children and added age categories between 12 years old to adulthood. We also administered our EVSP screening test to potentially non-typically developing individuals who were also assessed with the WISC-IV and other traditional clinical evaluations in the context of neurodevelopmental disorder diagnosis. Since we could have access to the results of this clinical assessment, we could establish which clinical tests are correlated with our EVSP screening test (concurrent validity) and which ones are not (divergent validity).

METHOD:

1. Participants' recruitment

487 participants (or their carers) gave written informed consent to this prospective research on the screening test of Elementary Visuo-Spatial Perception (EVSP) and to anonymous publication of the results. A total of 224 individuals were recruited in the context of research calls (CPP Sud-Est II, n° 2009-036-AM3-2): 100 teenagers with typical or non-typical development completed the previous sample of 96 typically developing children aged between 4 and 12 recruited from a school (together with 24 adults and the 2 stroke patients recruited to evaluate the typical development of EVSP and the neuroanatomy underlying the screening test[1]). In addition, a total of 263 children and teenagers were seen in the context of an out-patient consultation at the paediatric rehabilitation unit of the Hospices Civils de Lyon for a potential neurodevelopmental langage, motor, attentional or learning disorder (with approval of the Research Ethic Boards of the University Hospital of Lyon CPP Sud-Est II, n°2015-54-2) and 209 passed through the inclusion (normal or corrected-to-normal visual acuity) and exclusion (cerebral palsy, epilepsy, autistic spectrum disorder or other behavioural or intellectual disability) criteria.

2. Data base of the present study

We ended up to analyse the EVSP data of 407 children and teenagers distributed in 6 age categories: between 4 (included) and 6 years old (excluded), between 6 (included) and 8 years old (excluded), between 8 (included) and 10 years old (excluded), between 10 (included) and 12 years old (excluded), between 12 (included) and 15 years old (excluded), between 15 (included) and 18 years old (excluded) (see figure 1). We isolated a group of 223 individuals presenting with non-typical development potentially altering EVSP (neurodevelopmental disorder according to the DSM V criteria and interdisciplinary neuropsychological testing (n=161), pre-term birth before 37 gestational weeks without cerebral palsy and MRI (n=48), impaired binocular vision (n=14)) and a group of 184 typically developing children and teenagers (TD). We collected retrospectively the quantitative clinical assessments that several of these individuals received in the hospital or elsewhere over the last two years. The most available battery was the WISC IV[17]. Fewer individuals were assessed with the M-ABC[18], the BHK[19], the Purdue Pegboard Test[20,21], the Block test of Benton[22], the subtests Visuomotor precision, Imitating hand positions, Design copying, Block construction and Arrows of the NEPSY-II[23], or the non-motor subtests and the subtest Spatial relationships of the DTVP-2[24] in the context of a suspicion of Developmental Coordination Disorder (DCD).

3. The EVSP screening test

The exact metrics of all the stimuli are available in previous publication[1] and the entire test can be downloaded from the supplementary information on-line (http://dx.doi.org/10.1016/j.neuropsychologia.2012.11.015).

The EVSP screening test (figure 2) is composed of 6 subtests presented in the order T1 to T6. Subtests T1, T2, T3, and T5 relied on image-pair comparisons (or trials) that require a ‘‘same’’ or ‘‘different’’ response. Subtest T4 required a ‘‘midline’’ or ‘‘not midline’’ answer and subtest T6 required to name the colour of the selected dot (pinpointing was accepted). Each of the six subtests included 12 trials. Six ‘‘identical’’ and six ‘‘non-identical’’ image-pairs within each subtest were intermingled pseudo- randomly. The trials whose correct response was ‘‘different’’ (or ‘‘not midline’’ for T4) were presented in order of increasing difficulty. The twelve trials of T6 were presented in order of increasing number of distractors.

Testing conditions :

The participant was comfortably seated in front of a table on which the visual stimuli were presented in turn on cardboard sheets without any time constraints. Each subtest began with two easy training trials for which the experimenter gave the correct responses. The entire test

was expected to last no more than 15 minutes, even in young children and in children with neurodevelopmental disorder.

Scoring :

For each participant, using the 12 binary responses for each trial (‘‘correct’’ vs. ‘‘incorrect’’), we first computed the score for each subtest (range 0–12) and then the global score (best performance: 12x6= 72). The raw scores of the individuals of the typically developing group were used to compute the median (M) and the mean, the lower and higher limits of the interquartile range (named Q1 and Q3, respectively) and the lower and higher outlier limits (OL_sup = Q3 + 1.5 x interquartile range; OL_inf = Q1 - 1.5 x interquartile range) of the normative distributions for each age category.

4. Statistical analysis

Statistical analyses have been performed using Statistica and R. Statistical threshold was fixed to 5% but when 1% is reached it is mentioned.

Internal consistency:

The alpha coefficient of Cronbach was calculated on the raw scores of controls in order to evaluate the internal consistency of the EVSP screening test. The inter-correlation between items of a clinical test should be high (>0.7) but not too close to 1, as its aim is to be specific (to measure a unique function, here EVSP) without redundancy between the subtests in order to be fast and efficient.

Test-retest reliability:

In order to evaluate the test-retest reliability of the screening test of EVSP, we took the opportunity to test, when possible, several individuals twice in similar conditions with a variable delay in-between ranging between 2 weeks and 4 months, which could make them change age category. The group we could constitute included 12 children with neurodevelopmental disorder, 12 children with typical neurodevelopment and the patient CF with occipito-parietal lesion previously published[1]. The statistical comparison was performed on the raw value of the global score obtained with the EVSP screening test (that could vary between 0 and 72) and on the class numbers. The test-retest effect was evaluated using a Wilcoxon test. The intra-class correlation coefficient (ICC) was estimated using a Spearman correlation analysis. The ICC ranges between 0 and 1 and is considered satisfactory when it is above 0.5[25].

Non-parametric correlations :

In order to evaluate the criterion-related validity and the construct validity of the EVSP screening test, we assessed the functional relationship between EVSP and other clinical tests of motor and cognitive performance by calculating the Spearman’s correlation coefficient Rho.

The Rho coefficient of Spearman is a measure of effect size (Rho = 0.1 is small; Rho = 0.3 is medium; Rho = 0.5 is large)[26]. Because our retrospective data provided very different sample sizes (N), due to the variety of clinical tests and of their age range validity, we also provide the variance V of each correlation effect size using the formula $V=((1-Rho^2)^2)/(N-1)$.

To this aim, we needed to do statistical analyses with all data independently of age category. The scores of individuals were compared to the normative limits of their age category (Table 1) and converted into 6 classes (<OL_inf: class 1; OL_inf<= x <Q1: class 2; Q1<= x <M: class 3; M<= x<Q3: class 4; Q3<= x <OL_sup: class 5; >=OL_sup: class 6)

RESULTS

1. Score evolution with age

Table 1 provides an update of the normative samples limits of the EVSP screening test global score already published[1]: median, interquartile range (boxes) and outlier limits (whiskers) of the typically developing group for each age category. In clinical routine, the raw score of an individual (for example with neurodevelopmental disorder) must be compared with the performance of typically-developing individuals of the same age category. We propose that if the score is below the inferior outlier limit, it is surely pathological. If the score is in-between the inferior outlier limit and Q1, it is a low score (at risk).

As already observed[1], these data confirm with more subjects that in typically developing individuals the mean raw scores increase and standard errors decrease with age (figure 3). In our heterogenous group of non-typically developing individuals, the increase of the global score with age appears less steep and the decrease of variability less early. Note that in this group of non-typically developing individuals the data for the youngest age category are not reliable because the sample size is very small (n=8).

2. Content validity

The distributions of responses at the EVSP screening test have been further studied by sub-test. A ceiling effect is observed only for T6 which has a different response modality than the other subtests involving a selection among coloured dots. Interestingly, we have observed that while the presence of colour and of a multi-choice in T6 boosts the performance of typically developing individuals (with respect to T5 which evaluates the same allocentric position comparison with a « same » - « different » response), it can instead create additional difficulties in individuals with EVSP deficit. For all scores, the Skewness test indicates that the distribution of responses by age category is asymmetrical with lower values being more frequent than higher ones. The Kurtosis test indicates that the distribution is leptokurtic rather than gaussian, which justifies the use of non-parametric statistical tests.

3. Internal consistency

Internal consistency between the 6 subtests of the EVSP screening test was evaluated on the 210 typical developing individuals. It is good (with Cronbach alpha coefficient = 0.758) with a relatively precise 95% confidence interval between 0.697 and 0.805.

4. Test-retest reliability

The global score of 25 individuals tested twice in similar conditions were compared using a Wilcoxon test which revealed no statistical difference between the test and the re-test ($Z=1.06$; $p=0.29$). Spearman's Rho between the test and re-test global scores was 0.76, (p-value <0.05). The class numbers were also compared using a Wilcoxon test which revealed no statistical difference between the test and the re-test ($Z=0.59$; $p=0.55$). Spearman's Rho between the test and re-test class numbers was 0.63 (p-value <0.05).

5. Criterion-related validity

According to Wechsler[17], four subtests of the WISC-IV should provide measures of visuo-spatial abilities: Block Design which evaluates visuo-constructive abilities, Coding which evaluates the ability of visuo-spatial analysis together with motor coordination, Symbol Search which evaluates the ability of visual analysis and discrimination of complex graphical shapes and Matrix Reasoning which measures fluid and visuo-spatial intelligence. In order to evaluate criterion-related validity, we therefore computed the Pearson coefficients Rho for the correlation between the classes converted from the raw global scores obtained at the EVSP screening test and the scores (also independent of age category) obtained at these subtests. Table 2 present the results of these correlations, together with the correlations with other clinical measures that were either significant or with high effect size (Rho).

Criterion-related validity of the EVSP screening test is good, as it correlates significantly with Matrix Reasoning ($n=149$, $Rho=0.33$, $p<0.01$), Block Design ($n=151$, $Rho=0.23$, $p<0.01$), Symbol Search ($n=149$, $Rho=0.20$, $p<0.05$) and Coding ($n=148$, $Rho=0.17$, $p<0.05$). As a result, the EVSP screening test correlated 0.33 with Perceptual Reasoning Index (PRI, $n=171$, $p< 0.01$) and there was a trend of correlation with the Processing Speed Index (PSI, $n=163$, $Rho=0.15$; $p=0.057$).

Interestingly, one of the highest Rho correlation coefficient was found with the subtest Arithmetics of the WISC-IV ($n=16$, $Rho=0.63$, $p<0.01$) which pertains, together with the digit spans subtests, to the Working Memory Index (WMI) of the WISC-IV also correlating significantly with EVSP ($n=89$; $Rho=0.25$; $p<0.05$).

In contrast, no correlation was expected between the EVSP screening test and oral language. Accordingly, the Pearson's Rho with the Verbal Comprehension Index was not significant ($n=163$; $Rho=0.14$; $p>0.05$).

Other scores were collected retrospectively in the context of potential DCD diagnosis. Among the classical motor coordination assessments, the scoring class at the EVSP screening test correlated with tests of visuo-constructive abilities (Block of Benton : n=12, Rho=0.61, p<0.05 ; Block of NEPSY-II : n=87, Rho=0.30, p<0.01) but also with fine visuomotor control tested by the Purdue Pegboard Test (unimanual score: n=26 , Rho=0.55 , p<0.01; bimanual score: n=25, Rho=0.41, p<0.05; Assembly: n=25, Rho=0.36, p=0.08) and by the Manual dexterity score of the MABC (n=62, Rho=-0.30, p<0.05). In contrast, no correlation and very small Rho coefficient were found between EVSP and the two other scores of the MABC (namely Aiming & Catching n=55, Rho=-0.04 and Balance n=55, Rho=0.04) leading to non-significant correlation with the total score of the MABC (n=61, Rho=-0.10, p>0.05). The EVSP screening test also correlated with paper-and-pencil tests like Spatial relationship of the DTVP-2 (n=10; Rho=0.84; p<0.01) and there was a trend of correlation with Design Copying of NEPSY-II (n=73; Rho=0.20, p=0.09). No correlation was found between EVSP and handwriting ability assessed by the BHK (neither with the quality score n=75; Rho=-0.14, p=0.23, nor for the speed score n=78; Rho=-0.03, p=0.75).

Note that, among the best correlation coefficients obtained, the EVSP screening test correlates 0.43 with the subtest Arrow of NEPSY-2 (n=15) and the non-motor score of the DTVP-2 (which includes Closure, n=11, Rho=0.27; Position in space, n=13, Rho=0.23; Figure-Ground, n=10, Rho=0.26; Shape constancy, n=8, Rho=0.29), but none of these correlations did reach significance, probably because the number of data points was insufficient.

DISCUSSION :

The EVSP screening test lasts only 15 minutes and allows to assess in isolation the perceptual abilities of the dorsal visual stream in children as well as in adults[1]. The present study provides performance of typically-developing individuals at different age categories starting at 4 years old and validates the EVSP screening test as it shows good test-retest reliability and internal consistency (both at 0.76).

The criterion validity is also satisfactory. It was confirmed by the significant correlation of the EVSP screening test with the subtests Matrix Reasoning, Block Design, Coding and Symbol Search of the WISC-IV, known to involve visuo-spatial processing. As a consequence, it also correlates with the Perceptual Reasoning Index and, there is a trend with the Processing Speed Index. Interestingly, one of the highest Rho correlation coefficient was found with the subtest Arithmetic of the WISC-IV which pertains to the Working Memory Index of the WISC-IV also correlating significantly with EVSP. This result fits with hypotheses that logico-mathematical skills commonly involve visuo-spatial mental representations[27] as a support for example to explore and recall linear relationships (ordinal memory and reasoning). Finally, the

lack of correlation with the Verbal Comprehension Index adds to its validity by confirming its specificity, since EVSP was not expected to have any relationship with oral langage.

The EVSP screening appears useful to provide a differential diagnosis within categories of neurodevelopmental disorders characterized by high profiles heterogeneity. For example, it could be useful to determine those DCD children who present with EVSP deficit and those who don't, in order to tailor the rehabilitation program and scholar preconisations. The EVSP screening test is correlated with some subtests used to diagnose Developmental Coordination Disorder (like Manual dexterity of the MABC and Block tests) but not others (like Aiming & Catching and Balance of the MABC, Handwriting as tested by the BHK). The EVSP screening test is thus correlated with traditional clinical tests also evaluating visuo-spatial abilities but far longer to administer and less specific. It is faster and easier to use in order to rule out or evidence a visuo-spatial processing impairment that could contribute at varying degrees to neurodevelopmental disorder. The EVSP screening test could be used to evaluate the prevalence of such troubles within the neurodevelopmental disorder categories.

The EVSP screening test could also be useful to medical doctors for an early detection of children at risk for neurodevelopmental disorder. Because it does not involve a motor response, it can be used even to evaluate EVSP in individuals with motor disorder in which EVSP may also be impaired, for example in cerebral palsy[28,29].

The limitation of the present study is the retrospective data collection of clinical data which led us to select the subtests of the WISC-IV, most frequently used in clinical assessment, for criterion-related validity. The non-motor score of the DTVP 2 and the arrows subtest of the NEPSY-II are considered more specific of basic visuo-spatial skills. However, even if too few data were collected from these more specific tests to reach significance, the effect size of the correlations between them and our screening test was medium to high: 0.43.

Another limitation is the recruitment of non-typically developing individuals mainly from out-patient consultations leading to a small number of data at the earliest age category, due to the scarcity of clinical detection of neurodevelopmental disorder below 6 years old.

To conclude, these results are in favor of using the EVSP as a valid, easy, fast, but specific test to evaluate visuo-spatial processing ability in children. It could potentially be used for early screening as well as for differential diagnosis and rehabilitation in the context of neurodevelopmental disorders. A generalization of its use could bring more data allowing to better characterize a visuo-spatial profile of neurodevelopmental disorder.

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Age Category	Sample size	Mean Score	Standard Error	OL_inf	Q1	Median	Q3	OL_sup
[4-6[	N=24	49.4	5.06	42	45	49	53.5	58
[6-8[	N=32	58.0	4.52	45	54.5	59	61	65
[8-10[	N=38	60.3	4.77	49	57	61	63	68
[10-12[	N=42	61.9	3.76	54	60	62.5	65	69
[12-15[	N=30	62.1	3.59	55	59	62	65	68
[15-18[	N=18	62.5	2.98	57	61	63	64	67

Table 1 : Normative values for the EVSP screening test global score

(typically developing group)

StandardsTests :	N	Variance of Rho	Correlation coefficient Rho
Subtest Spatial relationships DTVP-2	*10*	*0.010*	*0.84***
Subtest Arithmetic WISC-IV	*16*	*0.024*	*0.63***
Block of Benton	*12*	*0.036*	*0.61**
Purdue Pegboard: unimanual score	*26*	*0.019*	*0.55***
Arrows of NEPSY-II	*15*	*0.047*	*0.43*
Non-motor score of DTVP-2	*7*	*0.111*	*0.43*
Purdue Pegboard: bimanual score	*25*	*0.029*	*0.41**
Purdue Pegboard: assembly	*25*	*0.032*	*0.36*
Subtest Matrix Reasoning WISC-IV	*149*	*0.005*	*0.33***
Perceptual Reasoning Index *WISC-IV*	*171*	*0.005*	*0.33***
Block construction NEPSY-II	*87*	*0.010*	*0.30***
Manual dexterity MABC	*62*	*0.014*	*-0.30**
Working Memory Index WISC-IV	*89*	*0.010*	*0.25**
Subtest Block Design WISC-IV	*151*	*0.006*	*0.23***
Subtest Symbol Search WISC-IV	*149*	*0.006*	*0.20**
Design Copying of NEPSY-II	*73*	*0.013*	*0.20*
Subtest Visuomotor precision DTVP-2	*33*	*0.030*	*0.19*
Subtest Coding WISC-IV	*148*	*0.006*	*0.17**

***p-value < 0.05**

****p-value < 0.01**

Table 2: Correlation between standard clinical tests and the class of scoring at the EVSP screening test (from 1 to 6). The list is presented in the order of decreasing absolute values of Rho, for values of Rho>0.15.