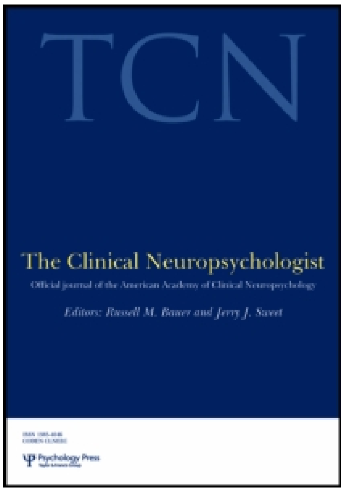

The Clinical Neuropsychologist
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713721659

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First Published on: 13 February 2009

To cite this Article La Femina, Floriana, Senese, Vicenzo Paolo, Grossi, Dario and Venuti, Paola(2009)'A Battery For The Assessment of Visuo-Spatial Abilities Involved in Drawing Tasks',The Clinical Neuropsychologist,

To link to this Article: DOI: 10.1080/13854040802572426

URL: http://dx.doi.org/10.1080/13854040802572426

The Clinical Neuropsychologist, 2009, 1–24, iFirst
http://www.psypress.com/tcn
ISSN: 1385-4046 print/1744-4144 online
DOI: 10.1080/13854040802572426

A BATTERY FOR THE ASSESSMENT OF VISUO-SPATIAL ABILITIES INVOLVED IN DRAWING TASKS

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Drawing ability is a complex cognitive process that involves different aspects of visuo-spatial skills. To date, the link between these functions has not been deeply investigated because of the absence of a standardized test that globally analyzes the basic aspects of visuo-spatial processes. The aim of this study was to examine the dimensionality, reliability, and validity of a new battery assessing basic visuo-spatial abilities implied in drawing tasks. A total of 370 children (aged 4–11 years) participated in the study. In order to analyze the psychometric properties of the battery subscales, data were analyzed with a Rasch model and compared with other standardized tests. For each subscale items were compared and ordered on the latent trait, and the misfitting items eliminated. The results of this study provide evidence for the reliability and validity of the battery, and indicate that the battery can be a valid tool for researchers interested in investigating the development of visuo-spatial abilities and the relationship between basic visuo-spatial abilities and general cognitive abilities.

Keywords: Spatial cognition; Visuo-spatial abilities; Drawing abilities; Constructional abilities; Rasch model.

INTRODUCTION

Spontaneous drawing or copying of an object is a unique and important activity that only humans can perform. Drawing performance is often used for the identification of cognitive impairments in adults, as it is quick and easy to administer and sensitive to degeneration processes (Ericsson, Forssell, Holmen, Viitanen, & Winblad, 1996). In the literature the majority of the studies investigate adults' drawing abilities, whereas there are only few studies about children's drawing abilities. In this work we aim to investigate the visuo-spatial processes implied in children's copy drawing by developing a battery to assess basic visuo-spatial processes.

When participants reproduce a simple or complex shape they have to plan the sequence of the elements to be drawn and they have to consider the spatial relations among them. From this point of view, then, drawing can be better thought of as a particular kind of constructional task. According to Benton (1967), constructional

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Accepted for publication: October 21, 2008.

abilities are all the activities that require the capacity to analyze different elements within a visual model, the ability to assess the spatial relations between the single parts and the whole structure, and the capacity to reproduce this model. Several studies (Bensur, Eliot, & Hedge, 1997; Freedman et al., 1994; Guerin, Ska, & Belleville, 1999) have shown that constructional abilities are not linked exclusively to simple motor skills but are correlated to visuo-spatial cognition processes such as visuo-spatial perception, spatial representation, visuo-spatial working memory, motor planning, and executive functions. From this point of view, it is important to highlight that the perceptual and representational aspects refer to two levels of information processing of different complexity (De Renzi, 1982): Visuo-spatial perception skills refer to the stimulus-driven processing of the structural aspects of a stimulus, such as size, shape, orientation, and the spatial relationships of the stimulus with other objects and with the observer. However visuo-spatial representational skills, such as mental image rotation or assembling abilities, are complex mental processes concerning the ability to operate upon information while making reference to internal representations loaded from long-term memory (De Renzi, 1982; Farah, 1984; Kosslyn, 1994). Deficits in constructional abilities can be found both in adults (Benson & Barton, 1970; Kleist, 1934; Piercy, Hecaen, & Ajuriaguerra, 1960) and in children with different developmental disorders (Del Giudice et al. 2000b; Eden, Stein, Wood, & Wood, 1996; Eden, Wood, & Stein, 2003; Gray, Karmiloff-Smith, Funnell, & Tassabehji, 2006; Mammarella & Cornoldi, 2005; Mati-Zissi & Zafiropoulou, 2003; Ramus, 2003). While adults' constructional abilities and related disorders constitute a specific area of cognitive neuropsychological research (Blair, Kertesz, McMonagle, Davidson, & Bodi, 2006; Cormack, Aarsland, Ballard, & Tovee, 2004; Schmidtke & Olbrich, 2006; Smith, Gilchrist, Butler, & Harvey, 2006; Trojano et al., 2005; Trojano & Grossi, 1998), only a few studies have examined constructional abilities in children with typical and atypical development (Akshoomoff & Stiles, 1995a, 1995b; Cohen, Ricci, Kibby, & Edmonds, 2000; Del Giudice et al., 2000a, 2000b; Dilworth, Greenberg & Kuschè, 2004; Friedman & Laycock, 1989; Tada & Stiles-Davis, 1989; Vakali, 1991).

To date the neuropsychological assessment of children's constructional abilities consists either in tasks based on assembling and building two- and three-dimensional patterns or in spontaneous drawing and copying (for review, see Grossi, Conson, & Trojano, 2006; Grossi & Trojano, 2001; Lezak, 1995). In the latter case the tools commonly used are: the Rey-Osterreith Complex Figure (Rey, 1941), the Visuo-Motor Integration Test (Beery, 1995), the Bender Gestalt test (Bender, 1938), the Clock Drawing Test (Cohen et al., 2000), and the Bicycle Drawing Test (Kolb & Wishaw, 1990; Piaget, 1930). All these tests give information on the drawing procedures used, the number of elements accurately reproduced, and the constructive ability level reached by the participant compared to the typical healthy population. However, none of these tests is able to disentangle the specific cognitive processes implied in the task execution. Therefore, an extensive assessment of drawing ability would also require measurement of the main cognitive abilities that presumably underlie this activity. Although there are different standardized tests for the assessment of visuo-spatial abilities—such as the Developmental Test of Visual Perception (Hammill, Pearson, & Voress, 1993), the Visuo-Motor Integration Test (Beery, 1995), and the Benton Judgment of Line Orientation

Test (Benton, Sivan, Hamsher, Varney, & Spreen, 2000)—no one test is specifically designed to evaluate the basic visuo-spatial components entailed in drawing tasks. This is probably due to the absence of a homogeneous operative definition of visuo-spatial cognition, and of a specific theoretical model that explains the role of the different cognitive processes in drawing tasks (Akshoomoff & Stiles, 1995a). So, for a wider comprehension of the cognitive processes entailed in drawing tasks, it is necessary to devise and validate a tool that can analytically assess the cognitive functions implied in the execution of such constructional tasks. Moreover, such a tool should be based on a specific cognitive model of drawing abilities.

Some authors (Angelini & Grossi, 1993; Roncato, Sartori, Masterson, & Rumiati, 1987; Van Sommers, 1989) have studied the cognitive processes involved in spontaneous drawing and copying, and have proposed cognitive models that describe their functional architectures. Our work is inspired by the model elaborated by Grossi and colleagues (Grossi et al., 2002, 2006; Trojano et al., 2005; Trojano & Grossi, 1994). According to the model, the copying processes are carried out in four steps: preliminary analysis, preparation of drawing plan, execution, and control processes. In the preliminary analysis the participant carries out a visuo-spatial analysis of the figure by identifying its elements and analyzing the spatial relations among the elements, and between these elements and the sheet where the figure is drawn. In the next step, the participant prepares the drawing plan, and defines the procedural choices related to the sequence of elements to be reproduced. The constructional plan is kept in a short-term memory buffer as long as necessary for its translation into a specific motor program sequence. The executive step starts with the execution of the drawing. This latter phase is regulated by continuous monitoring activity that enables the participant to check the accuracy of their drawing with reference to the target figure. Therefore, according to the model, an unsuccessful production could be caused equally by an alteration of the attentive and visuo-perceptual processes, by an alteration of spatial representational abilities, by a limitation in programming and planning abilities, or by a defective hand–eye coordination (Cohen et al., 2000; Freedman et al., 1994; Gainotti, 1985; Grossi & Trojano, 2001; Ishiai, Sugishita, Ichikawa, Gono, & Watabiki, 1993; Sunderland et al., 1989).

On the basis of this model, the authors devised a battery for diagnosis and rehabilitation of adults suffering from brain injury—known in Italy by the acronym TeRaDiC (*La terapia razionale dei disturbi costruttivi*, Rational Therapy of Constructional Disorders; Angelini & Grossi, 1993; Trojano et al., 2005). The battery has also been used with typically developing kindergarten children (Del Giudice et al., 2000a).

Since the TeRaDiC battery was not specifically designed for assessing children, the aim of the present work was to adjust it and create a new neuropsychological battery for the evaluation of children's basic visuo-spatial processes that underlie drawing ability. For this purpose the adult battery was thoroughly modified, keeping its original structure substantially intact. The new battery, the Spatial Ability Test (TAS), has been administered to a sample of children aged 4 to 11 years, in order to prove its reliability and validity. To estimate the reliability indices a Rasch measurement model was considered. To estimate the concurrent validity indices several standardized tests that measure similar constructs were administered. To estimate the discriminant validity indices standardized tests that measure different constructs were administered.

Finally, according to Grossi and colleagues' drawing model that assumes a strong connection between constructional tasks and visuo-spatial abilities, in this study we analyzed the relation between the basic visuo-spatial abilities measured by the TAS and the copy drawing abilities measured by the Bender Gestalt Test (BGT; Bender, 1938). We hypothesized that the score on the constructional task would be associated with the scores on the visuo-spatial tasks.

METHOD

Participants

The participants were 370 children (198 female, 172 male) recruited from schools located in four Italian town districts (Rovereto, Verona, Napoli, and Caserta). The children were aged between 4 and 11 years (mean age = 6.8; $SD = 2.1$); 90.3% of them were classified as right-handed and 9.7% as left-handed. The children showed a wide range of IQ measured through Raven Colored Progressive Matrices (range: 5th to 95th percentile) (Mahone et al., 2002). As we were interested in the visuo-spatial abilities of typically developing children, we excluded all children having any clinical diagnosis of neuropsychological or psychological disease that could influence cognitive performance, such as mental retardation, pervasive developmental disorders, attention deficit hyperactivity disorder, and specific learning disability. Information about diagnosis was gained from a review of medical records released to the schools.

Parents and school teaching staff gave their informed consent for the children to participate in the study.

Materials

The Spatial Abilities Test (TAS) battery comprises five sections: Visual Analysis, Preliminary Task Analysis, Central Task Organization, Visual-Motor Coordination, and Execution. Each section comprises several subscales assessing specific cognitive processes. For each subscale there are two practice items in order to be sure that the child clearly understands the instructions. Time and correct answers are registered for each subscale.

Section one: Visual Analysis. This section offers a measure of the drawing procedure's first step, i.e., the ability to detect the existing elements in the spatial field. It consists of four visual search tasks: two of these assess the ability to detect all the stimuli presented in the spatial field (visual exploration) and the others assess the ability to detect a specific target while neglecting irrelevant stimuli (selective attention) (see Figure 1). To evaluate mastery in these processes we presented a low stimulus-density trial as well as a high-density one.

In the Visual Exploration scale (VE) participants are presented with 30 dots (first trial) and 60 dots (second trial) on a sheet, and must detect and mark the dots as quickly as possible. For each trial each item correctly marked is scored 1 (score range: 0–90). In the Selective Attention scale (SA) participants are presented with 40

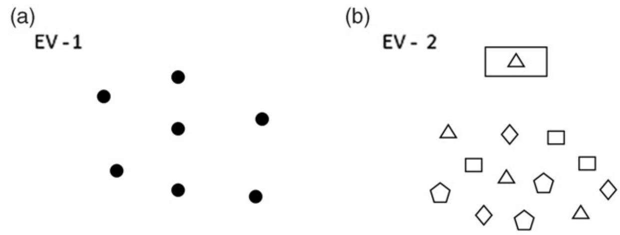

Figure 1 Examples of Visual Analysis section subscale trials. (a) Visual Exploration scale (VE); (b) Selective Attention scale (SA).

geometric shapes (first trial) and 80 geometric shapes (second trial) on a sheet, and must detect and mark any triangles as quickly as possible. There are 8 triangles in the first trial and 20 in the second one. For both trials each item correctly marked is scored 1 (score range: 0–28). Moreover, in both subscales (VE and SA), the number of omissions and their spatial position (left or right) are also recorded.

As highlighted by Del Giudice and colleagues (2000a) almost all typically developing children have acquired visual search abilities by the age of 4 years. Accordingly, in our sample all participants achieved the maximum score in the trials of this section and therefore results of the analysis for these scales are not reported. However, we considered it important to administer this section in order to exclude the presence of visual exploration or selective attention deficits that could influence performance on the other tasks of the battery and the drawing task.

Section two: Preliminary Task Analysis. Similarly, this section assesses the processes involved in the first step of the drawing procedure. Specifically it evaluates the ability to identify correctly the structural aspects of a stimulus. So we selected the main aspects of visuo-spatial perception such as shape, length, orientation, and the spatial relationships of the stimulus with other objects.

This section comprises four scales to assess visuo-spatial perception abilities (see Figure 2). Each scale consists of items of increasing complexity presented one by one on a sheet. For each item, a stimulus target and six distractors are presented. Participants have to indicate among the six alternatives the stimulus identical to the target. The subscales are:

(1) Line Length judgment (LL): In this subscale participants have to identify in the six-choice display the line with the same length as the stimulus. There are 12 items of increasing complexity as the linear differences among the target stimuli and distractors gradually decrease. Each correct choice was scored 1 (score range: 0–12);
(2) Line Orientation judgment (LO): In this subscale participants have to identify in the six-choice display the line with the same orientation as the stimulus. There are 12 items of increasing complexity as the differences in orientation among the target stimuli and distractors gradually decrease. Each correct choice was scored 1 (score range: 0–12);
(3) Spatial Relations judgment (SR): In this subscale participants have to identify in the six-choice display the square containing points in the same position as in the target stimulus. There are 12 items of increasing complexity as the number of

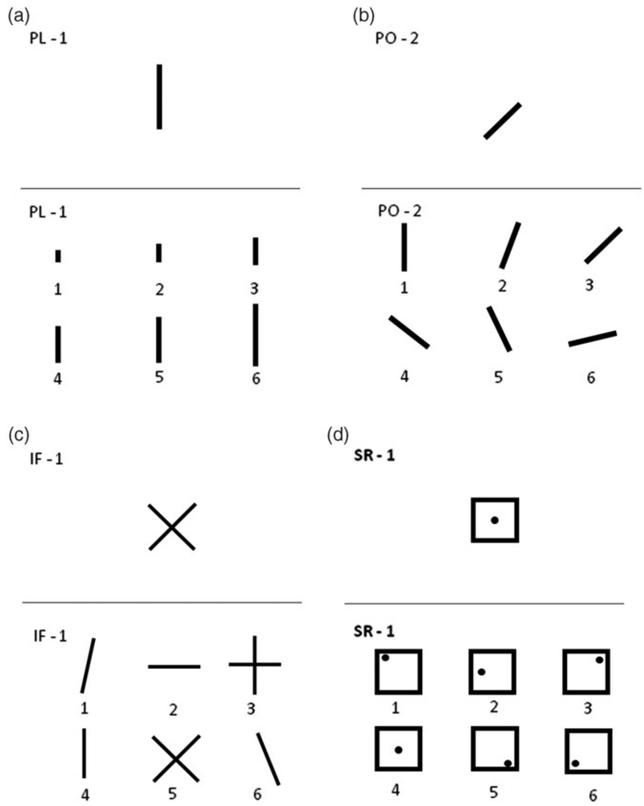

Figure 2 Examples of Preliminary Task Analysis section subscales trials. (a) Line Length judgment scale (LL); (b) Line Orientation judgment scale (LO); (c) Simple Shapes identification scale (SS); (d) Spatial Relation judgment scale (SR).

points (from one to three) increases and the differences among the target stimuli and distractors gradually decrease. Each correct choice was scored 1 (score range: 0–12);

(4) Simple Shapes identification (SS): In this subscale participants have to identify in the six-choice display the shape with the same features as the target stimulus. There are 12 items of increasing complexity as the differences among stimuli and distractors gradually decrease. Each correct choice was scored 1 (score range: 0–12);

Section three: Central Task Organization. This section assesses complex visuo-spatial processes concerning the ability to operate upon information while making reference to internal representations. Some of these abilities, such as complex figure identification and hidden figure identification, are involved in copy drawing of complex shapes such as the Rey-Osterreith Complex Figure; others are entailed in three-dimensional constructional tasks such as Block Design and Object Assembly of the Wechsler Intelligence Scales.

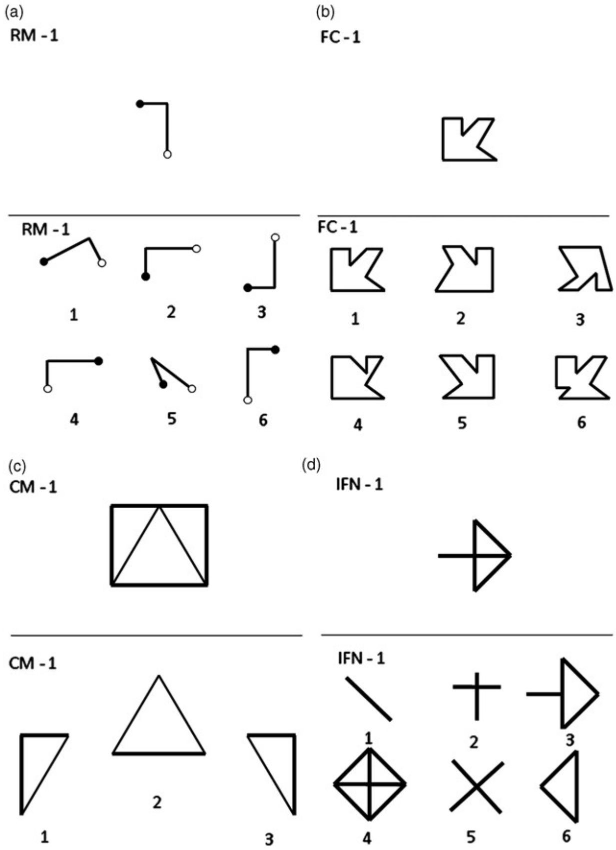

Figure 3 Examples of Central Task Organization section subscales trials. (a) Mental Rotation scale (MR); (b) Complex Figure identification scale (CF); (c) Mental Construction scale (MC); (d) Hidden Figure identification scale (HF).

Also in this section, each scale consists of items of increasing complexity presented one by one on a sheet. For each item a stimulus target and six distractors are presented. Participants have to indicate among the six distractors the stimulus identical to the target. This area consists of four subscales (see Figure 3):

(1) Mental Rotations scale (MR): In this subscale participants are presented a stimulus target shaped as the capital letter L or S, with small white or black circles at the extremities. The six-choice display encloses the target-item stimulus, rotated on the horizontal plan by 45°, 90°, 135°, or 180°, together with five distractors that are mirror forms of the target stimulus at different degrees of rotation. The task requires participants to indicate the only item in the display that matches the target. There are nine items of increasing complexity as the differences among stimuli and distractors gradually decrease. Each correct choice was scored 1 (score range: 0–9);
(2) Complex Figure identification (CF): In this subscale participants have to identify in the six-choice display the abstract figure identical to the

target stimulus. Target stimulus and distractors are geometrical shapes with no meaning. In this scale there are eight items of increasing complexity as the differences among stimuli and distractors gradually decrease. Each correct choice was scored 1 (score range: 0–8);

(3) Hidden Figure identification (HF): In this subscale participants are presented a target stimulus and six abstract figures as distractors. The task requires participants to identify in the six-choice display the complex figure embedded in the target stimulus. To give the correct answer, participants have to mentally disassemble the target stimulus. There are 12 items of increasing complexity as the differences among stimuli and distractors gradually decrease. Each correct choice was scored 1 (score range: 0–12);

(4) Mental Construction scale (MC): In this subscale the target stimuli consist of squares subdivided into parts, and randomly placed in the display. Participants have to identify the side with which the two components named by the examiner are contiguous in the stimulus. To give the correct answer, participants have to mentally assemble the distractors. There are 12 items of increasing complexity as the number of parts (from three to four) and similarity among distractors increase. One question is foreseen for each trial; each correct choice was scored 1 (score range: 0–12).

Section four: Visual Motor Coordination. This section assesses visuo-motor coordination abilities that represent the main aspects of the last step of the cognitive model of constructional skills. Participants are presented with five two-dimensional labyrinths of increasing difficulty on a sheet (see Figure 4). For each labyrinth they have to trace a line within the labyrinths from the start point to the end point (Line Drawing task, LD). Each trial is scored 1 if the participant traces the line without touching the limits (score range: 0–5).

Section five: Execution. This section assesses graphomotor skills. Participants are presented target matrices of several points and an identical drawing matrix. In the target matrix some points are linked by a line depicting a

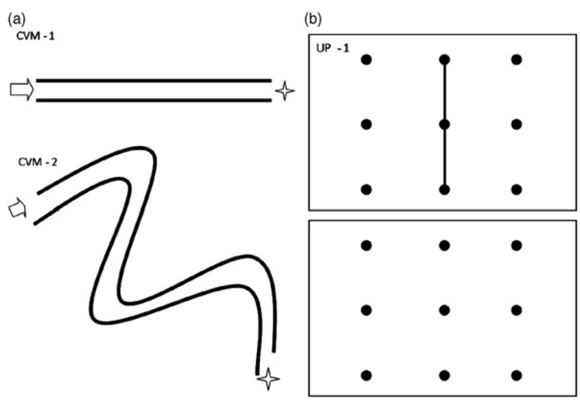

Figure 4 Examples of Visual Motor Coordination and Execution section trials. (a) Line Drawing task (LD); (b) Linking Points task (LP).

specific pattern (see Figure 4). The task requires participants to replicate the target pattern in the drawing matrix by linking points with a line (Linking Points task, LP). In this task, there are 12 target matrices of increasing complexity as the number of the matrix points (9 or 25) and the number of points linked in the pattern increase. Each trial is scored 1 if the participant reproduces the target pattern exactly (score range: 0–12).

As for the Visual Attention section, at 4 years of age almost all typically developing children have acquired the basic graphomotor and visual motor coordination skills measured by the TAS (Del Giudice et al., 2000a). In our sample all participants achieved the maximum scores, and for this reason results of the analysis for these scales are not reported. However, we considered it important to administer them in order to exclude the presence of graphomotor impairments that could influence performance on the other tasks and on the drawing task.

Procedure

Tests were administered in a quiet room of the school, where children were tested individually. For each task the time of execution and the correct answers were registered. Besides our visuo-spatial ability (TAS) battery, children were also given five standardized tests assessing visuo-spatial processing in order to verify the validity of the TAS.

The Visuo Motor Integration Test (VMI; Beery, 1995)—specifically the subscale that assesses the perception abilities—was administered in order to verify the validity of the Preliminary Task Analysis section of our battery. The VMI offers a global measure of perceptual ability that includes the capacity to identify the size, orientation, and shape of geometrical forms. However the instrument cannot assess the mastery level of the participant in different domains. In the VMI participants are presented 27 different target shapes and they have to identify a shape identical to the target among several distractors. High scores indicate high visual perception abilities.

The Raven Colored Progressive Matrices (CPM; Raven, 1976) were administered in order to validate the representational tasks of the Central Task Organization section of our battery. We selected the CPM as a criterion measure because many items of the CPM assess higher representational abilities, such as assembling single parts in a global configuration or identifying complex configurations. Specifically, according to the literature, the CPM measures at least two distinguishable factors: analogical reasoning and spatial visualization (Gustaffson, 1984, 1988; Hertzog & Carter, 1988). In fact, Van der Ven and Ellis (2000) split the analogical reasoning factor into further two factors identified as verbal-analytic reasoning and visuo-spatial ability. As mentioned by Mackintosh and Bennett (2005), the verbal-analytic reasoning factor also contains a small spatial ability factor. CPM includes 36 items and high scores indicate high nonverbal reasoning ability.

In order to assess the discriminant validity of the TAS, the Word Reading Scale and the Word Writing Scale of the Developmental Dyslexia and the Dysorthographia Assessment Battery (Sartori, Job, & Tressoldi, 1995) were administered to a subsample of 114 children (56 female, 58 male). In the Word

Reading Scale (WRS) participants are presented 112 (Italian) words and must read them as accurately and speedily as possible. In the Word Writing Scale (WWS) the experimenter dictates 48 (Italian) words and participants have to accurately write as many words as possible. For both tasks the number of errors is computed; therefore in this test high scores indicate low reading or writing abilities.

The Bender Gestalt Test (BGT; Bender, 1938) was administered in order to assess constructional abilities. In this task the participant is asked to copy eight geometrical shapes of various levels of difficulty. Drawings were encoded by the Koppitz scoring system (Koppitz, 1975). For each shape the scoring system presents an exhaustive drawing deformations checklist. Therefore in this test high scores indicate low drawing ability. As mentioned before, drawing is a particular constructional task. In this study we used the BGT because, compared to other constructional tools, it shows the same validity, faster administration, and a minor influence of cultural knowledge. As shown in the literature, the BGT is significantly correlated with the Visuo-Motor Integration Test (Knoff & Sperling, 2006) and with WISC III subtests assessing visual and spatial thinking (Decker, Allen, & Choca, 2006). As indicated by Decker et al. (2006), the Bender-Gestalt Copy test has commonality with the visual and spatial tasks, given the similarity in the visuomotor demands of each test. Moreover, the copy score on the Bender Gestalt Test was predicted to load on measures of visual and spatial thinking. According to the literature, in this study the BGT was considered a good measure of constructional abilities and a criterion measure to assess the validity of the cognitive drawing model (Angelini & Grossi, 1993).

In order to avoid tiring the children the test administration took place over 2 days. On the first day participants were submitted to the standardized tests in the following order: the nonverbal reasoning abilities test (CPM), the visual perception abilities test (VMI), the Word Reading Scale (WRS), the Word Writing Scale (WWS), and the constructional abilities test (BGT). The CPM, VMI, WRS, and WWS scales were administered on the first day. On the second day our visuo-spatial ability test (TAS) was administered.

Analyses

Dimensionality and reliability. In order to evaluate the psychometric properties of the TAS (dimensionality and reliability), given that each subscale is assumed to measure a unidimensional visuo-spatial ability, the data were submitted to a Rasch measurement model (Lord & Novick, 1968; van der Linden & Hambleton, 1997): the simple logistic model (SLM; Rasch, 1960/1980). This probabilistic model assumes that if a scale is unidimensional, the response to a dichotomous item depends exclusively on the relation between two components: the participant's ability (β) and the item's difficulty (δ). In mathematical terms, the relation between the two components is expressed by the logistic form:

$$P\left[X_{ni} = x_{ni} \middle| \beta_n, \delta_i\right] = \exp[x_{ni}(\beta_n - \delta_i)]/1 + \exp[x_{ni}(\beta_n - \delta_i)]$$

where X_{ni} is a random variable that could assume value of $x_{ni} = 1$ if the answer is correct and $x_{ni} = 0$ if it is incorrect; β_n is the position of the participant n on the latent dimension; and δ_i is the position of the item i on the latent dimension. Given the estimated parameters, respectively person measure and item calibration, the expected response pattern for each participant and for each item is determined by the model. When the observed response pattern does not systematically deviate from the expected one, then the items constitute a true Rasch scale. So the scale can be considered unidimensional and providing the Rasch model properties (Rasch, 1960/1980). If the scale does not equate to the model some fit statistics can be used to identify misfitting items. Misfitting items can be removed and the adequacy of the reduced scale can be evaluated. Once the analysis is over and the Rasch scale identified, the item parameters allow identification of the hierarchical order of difficulty of the items along the continuum of the latent trait. The item location along the continuum is expressed in log-odd units (logits), where logits of greater magnitude represent increasing item difficulty. By this index it is possible to identify whether the items measure the same ability level and to what extent the scale is able to test the continuum in a broad sense.

The psychometric properties of the scale were explored with the software RUMM 2010 (Andrich, Sheridan, Lyne, & Luo, 2000) and WINSTEPS 3.57 (Linacre, 2005). All the other analyses were performed through the R 2.4.1 statistical computing package (R Development Core Team, 2006).

To evaluate the fit between the data and the model we used the item–trait fit index for the full scale, and the standard residual and item–trait fit index for the evaluation of single item fit. The standard residual index is based on the comparison between the expected and observed responses expressed in standard points. The item–trait fit index, both for the full scale and for a single item, evaluates the adequacy of the response pattern to the model assumptions, subdividing the sample into G classes along latent continuum intervals, and then computing the residuals across the persons within each class. The residuals are expressed in chi-square terms. For the standard residuals we considered as misfits values greater than $|1.64|$, while for the item–trait fit index we subdivided the sample into three groups, and considered as misfits chi-square values with a p value lower than .05. To evaluate the reliability of the scales we used the person separation index (PSI). This index is a function of both the variance of the location of the persons and the error of measurement variance, and is a relevant statistic to consider in relation to specific violation of model fit. Finally, as suggested by Linacre (1998), the dimensionality of the scales was evaluated through a principal component analysis (PCA) of the standardized residuals. In this analysis it is expected that after removing the Rasch dimension (e.g., the specific visuo-spatial ability) the residuals of items should be uncorrelated and no relevant component should result.

Concurrent and discriminant validity. In order to evaluate concurrent and discriminant validity, the intercorrelations (Pearson's coefficients) among all the subscales and between the subscales and the selected criterion measures were computed (CPM, VMI, WRS, and WWS).

Model validity. According to the selected cognitive model (Angelini & Grossi, 1993), to evaluate the relationship between the TAS subscales and the constructional abilities we computed correlation between the subscales and the score on the Bender test (BGT). In all cases for the total score we have considered only the reliable and adequate items of the TAS. Finally, given the multiple hypothesis testing in the validity analyses, in order to control the increase in type I error we applied Hommel's correction to the *p*-values of the correlation coefficients (Hommel, 1988).

RESULTS

Dimensionality and reliability

Rasch analysis of the 12-item LL scale did not reveal a good item–trait fit for the full scale, $\chi^2(60) = 114.308$; $p < .00001$; PSI = .77, although adequate with standard residual items (mean items fit residual = .094; $SD = 1.181$). Following the analysis of the full scale we eliminated two items that showed misfit to the model expectations: item 2 (fit residual value = 1.605 and a chi-square *p*-value < .001) and item 1 (fit residual value = .715 and a chi-square *p*-value < .009). The 10-item LL scale revealed a good fit both for the full scale, $\chi^2(50) = 66.604$; $p = .06$; PSI = .75, and the items (mean items fit residual = .195; $SD = 1.03$). The PCA confirmed that the 10-item LL scale is unidimensional (variance explained by scores =68.0%; unexplained variance = 32.0%; variance explained by first factor = 4.4%). Individual items are presented in Table 1 with their location (δ) and fit indices.

Rasch analysis of the 12-item LO scale revealed a good fit for the full scale, $\chi^2(60) = 64.968$; $p = .31$; PSI = .78, and all the items (mean items fit residual = .141; $SD = 1.515$). The PCA confirmed that the 12-item LO scale is unidimensional (variance explained by scores = 84.4%; unexplained variance = 15.6%; variance explained by first factor = 1.8%). Individual items are presented in Table 1 with their location (δ) and respective fit indices (the standard residual index and the item–trait index).

Rasch analysis of the 12-item SR scale did not reveal a good item–trait fit for the full scale, $\chi^2(48) = 131.151$; $p < .00001$; PSI = .79, and standard residual values (mean items fit residual = .364; $SD = 2.337$). Following the analysis of the full scale we eliminated two items that showed misfit to the model expectations: item 12 (fit residual value = 5.439 and a chi-square *p*-value < .0001) and item 2 (fit residual value = 5.608 and a chi-square *p*-value < .0001). The 10-item SR scale revealed a good fit both for the full scale, $\chi^2(40) = 49.905$; $p = .14$; PSI = .81, and the items (mean items fit residual = .181; $SD = 1.407$). The PCA confirmed that the 10-item SR scale is unidimensional (variance explained by scores = 74.0%; unexplained variance = 26.0%; variance explained by first factor = 3.6%). Individual items are presented in Table 1 with their location (δ) and fit indices.

Rasch analysis of the 12-item SS scale did not reveal a good fit for the full scale, $\chi^2(36) = 213.350$; $p < .0001$; PSI = .70, and the items (mean items fit residual = −.429; $SD = 2.687$). Following the analysis of the full scale we eliminated two items that showed misfit to the model expectations: item 12 (fit residual value = 7.035 and a chi-square *p*-value < .0001) and item 10 (fit residual value = 1.709 and a chi-square *p*-value < .0001). The 10-item SS scale revealed a good fit both for the full scale, $\chi^2(30) = 32.157$; $p = .36$; PSI = .84, and the items (mean items fit residual = .312; $SD = 1.702$). The PCA indicated that the 10-item SS scale can be considered unidimensional (variance explained by

Table 1 Summary of Rasch psychometric statistics for the items of the TAS subscales

ITEM	Location (δ)	SE	Residual	Chi square	*p-value*	ITEM	Location (δ)	SE	Residual	Chi square	*p-value*	ITEM	Location (δ)	SE	Residual	Chi square	*p-value*
Line Length judgment scale [LL]						Line Orientation judgment scale [LO]						Spatial Relations judgment scale [SR]					
7	−1.588	.167	.300	8.237	.144	2	−3.379	.39	−.502	1.420	.922	4	−2.373	.310	.430	4.754	.313
10	−1.281	.156	2.151	11.098	.049	1	−2.065	.24	−1.058	3.543	.617	1	−1.543	.240	−1.479	2.378	.667
4	−1.130	.152	−.575	7.582	.181	3	−1.876	.23	−1.707	4.210	.520	5	−.990	.210	−.472	2.889	.577
5	−1.046	.149	−.624	7.045	.217	4	−.942	.18	−1.858	8.163	.147	3	−.632	.190	−1.275	4.549	.337
8	−.648	.140	.689	3.508	.622	5	−.272	.15	−.405	5.157	.397	9	−.457	.190	.977	5.545	.236
9	.440	.129	−1.398	9.463	.092	6	.097	.14	.557	6.164	.291	6	.291	.160	−.669	3.096	.542
11	.649	.129	1.231	2.187	.823	12	.134	.14	.751	1.634	.897	8	.728	.150	.186	6.304	.178
12	1.185	.131	−.244	5.437	.365	7	1.093	.13	1.741	3.179	.672	10	.875	.150	−.068	1.262	.868
3	1.432	.133	−.191	5.453	.363	8	1.445	.13	−.585	6.646	.248	7	2.049	.150	3.460	1.460	.033
6	1.989	.141	.614	6.595	.253	9	1.723	.13	3.435	9.776	.082	11	2.053	.150	.722	8.669	.070
						11	1.814	.13	.084	3.290	.655						
						10	2.227	.13	1.24	11.786	.038						
Simple Shape identification scale [SS]						Mental Rotation scale [MR]						Complex Figure identification scale [CF]					
4	−1.640	.390	.070	1.373	.712	1	−.711	.150	.494	3.150	.533	1	−1.457	.180	−1.634	8.963	.011
8	−1.372	.360	.064	1.760	.624	4	−.413	.160	2.641	7.893	.096	4	−1.100	.160	.058	1.452	.484
3	−.916	.320	−.207	1.166	.761	5	−.281	.160	3.738	8.834	.065	6	−.226	.140	3.209	3.987	.136
2	−.764	.300	−2.273	5.884	.117	3	−.277	.160	.748	6.886	.142	3	−.092	.140	.309	1.255	.534
1	−.704	.300	.514	3.198	.362	2	.097	.160	−1.246	7.166	.127	8	.542	.140	2.321	3.209	.201
7	−.565	.290	−.353	4.047	.256	8	.762	.170	.534	1.521	.823	5	.700	.140	.940	.073	.964
5	.874	.220	−1.183	6.352	.096	6	.824	.180	−.154	5.800	.215	7	1.634	.150	−.306	3.717	.156
9	1.477	.200	.302	.144	.986												
6	1.482	.200	2.471	5.415	.144												
11	2.128	.200	3.719	2.819	.420												

Continued

Table 1 Continued

ITEM	Location (δ)	SE	Residual	Chi square	*p-value*	ITEM	Location (δ)	SE	Residual	Chi square	*p-value*	ITEM	Location (δ)	SE	Residual	Chi square	*p-value*
Hidden Figure identification scale [HF]						Mental Construction scale [MC]											
1	−2.629	.180	−.680	7.559	.182	1	−1.786	.210	1.339	4.902	.428						
6	−2.548	.170	−.977	5.841	.322	7	−1.468	.200	.983	11.965	.035						
8	−1.817	.160	−.822	3.430	.634	5	−1.111	.190	.652	5.577	.350						
7	−.912	.150	.971	3.767	.583	2	−.875	.180	−1.143	4.624	.463						
4	.223	.160	−.460	2.422	.788	6	−.197	.170	.290	4.043	.543						
11	.442	.160	−.111	1.800	.876	4	.320	.170	−2.546	8.183	.146						
9	.503	.160	1.715	11.138	.049	11	.416	.170	−1.166	7.147	.210						
2	.678	.160	1.445	7.958	.159	12	.599	.170	−.344	5.120	.401						
12	1.396	.180	−.046	8.306	.140	3	1.152	.170	.957	2.315	.804						
5	1.510	.180	−1.175	2.993	.701	10	1.222	.170	−.975	15.499	.008						
10	3.154	.260	.333	5.409	.368	9	1.726	.180	−.653	1.761	.881						

Items are ordered by their position on the unidimensional latent trait; location = items location on unidimensional latent trait; *SE* = standard error of item location; Residual = standard residual fit index; Chi square = item-trait fit index; *p-value* = probability value of the item-trait fit index.

scores = 64.5%; unexplained variance = 35.5%; variance explained by first factor = 5.8%). Individual items are presented in Table 1 with their location (δ) and fit indices.

Rasch analysis of the 9-item MR scale did not reveal a good fit both for the full scale, $\chi^2(45) = 107.734$; $p < .0001$; PSI = .77, and the items (mean items fit residual = .597; $SD = 2.003$). Subsequently, according to the fit indices we eliminated two items that showed misfit to the model expectations: item 7 (fit residual value = 4.195 and a chi-square p-value < .0001) and item 9 (fit residual value = 2.963 and a chi-square p-value < .0001). The analysis on the 7-item MR scale revealed a good fit for the full scale, $\chi^2(28) = 41.252$; $p = .051$; PSI = .81, and the items (mean items fit residual = .965; $SD = 1.688$). The PCA indicated that the 7-item MR scale can be considered quite unidimensional (variance explained by scores = 59.8%; unexplained variance = 40.2%; variance explained by first factor = 9.5%). Individual items are presented in Table 1 with their location (δ) and respective fit indices.

Rasch analysis of the 8-item CF scale did not reveal a good fit both for the full scale, $\chi^2(40) = 89.574$; $p < .0001$; PSI = .75, and the items (mean items fit residual = .674; $SD = 2.020$). Subsequently, according to the fit indices we eliminated two items that showed misfit to the model expectations: item 2 (fit residual value = 4.167 and a chi-square p-value < .001). The analysis on the 7-item CF scale revealed a good fit for the full scale, $\chi^2(14) = 22.656$; $p = .07$; PSI = .75, and the items (mean items fit residual = .700; $SD = 1.633$). The PCA indicated that the 7-item CF scale can be considered quite unidimensional (variance explained by scores = 59.6%; unexplained variance = 40.4%; variance explained by first factor = 8.6%). Individual items are presented in Table 1 with their location (δ) and respective fit indices.

Rasch analysis of the 12-item HF scale did not reveal a good fit for the full scale, $\chi^2(60) = 83.207$; $p = .025$; PSI = .86, or the items (mean items fit residual = .062; $SD = 1.555$). According to the fit indices, we eliminated item 3 that showed misfit to the model expectations (fit residual value = 4.218 and a chi-square p-value < .001). The analysis of the 11-item HF scale revealed a good fit for the full scale, $\chi^2(55) = 60.624$; $p = .28$; PSI = .86, and for all the items (mean items fit residual = .017; $SD = .989$). The PCA confirmed that the 11-item HF scale is unidimensional (variance explained by scores = 90.3%; unexplained variance = 9.7%; variance explained by first factor = 1.2%). Individual items are presented in Table 1 with their statistics.

Rasch analysis of the 12-item MC scale did not reveal a good fit for the full scale, $\chi^2(48) = 86.588$; $p < .0001$; PSI = .92, or the items (mean items fit residual = –.121; $SD = 1.186$). According to the fit indices, we eliminated item 8 that showed misfit to the model expectations (fit residual value = .828 and a chi-square p-value < .01). The analysis on the 11-item MC scale revealed a good fit for the full scale, $\chi^2(55) = 71.136$; $p = .07$; PSI = .92, and for all the items (mean items fit residual = –.237; $SD = 1.192$). The PCA confirmed that the 11-item MC scale is unidimensional (variance explained by scores = 71.6%; unexplained variance = 28.4%; variance explained by first factor = 4.0%). Individual items are presented in Table 1 with their statistics.

Concurrent and discriminant validity

In order to evaluate the validity of the scales the correlation coefficients between the TAS battery subscales and the criterion measures were computed (see Table 2). The correlation analysis between the battery subscales showed a great association between the different subscales (mean correlation = .603; range = .352 – .724).

To evaluate the validity of the scales of the second section (Preliminary Task Analysis) the association coefficients between the subscales (LL, LO, SS, and SR) and the VMI scale were computed. As showed in Table 2, the results highlight significant associations between the VMI and all the Preliminary Task Analysis scales: the Line Length scale (LL, $r = .46$; $n = 220$; Hommel adjusted p-value $< .001$), the Line Orientation scale (LO, $r = .46$; $n = 220$; Hommel adjusted p-value $< .001$), Simple Shape identification (SS, $r = .36$; $n = 220$; Hommel adjusted p-value $< .001$), and the Spatial Relations scale (SR, $r = .55$; $n = 220$; Hommel adjusted p-value $< .001$).

In order to evaluate the validity of the Central Task Organization scales, Pearson's correlation coefficients were computed between Raven's test score and the subscales of the third section that evaluates representational abilities (MR, CF, MC, and HF) (see Table 2). The results highlight a significant association between Raven's test score (CPM) and all the Central Task Organization scales: the Mental Rotation scale (MR, $r = .55$; $n = 220$; Hommel adjusted p-value $< .001$), the Complex Figure identification scale (CF, $r = .68$; $n = 220$; Hommel adjusted p-value $< .001$), the Mental Construction scale (MC, $r = .75$; $n = 220$; Hommel adjusted p-value $< .001$), and the Hidden Figure identification scale (HF, $r = .71$; $n = 220$; Hommel adjusted p-value $< .001$).

In order to evaluate the discriminant validity of the scales, correlation coefficients were computed between the TAS battery subscales and the criterion measures. As showed in Table 2, the results highlight non-significant associations between the Word Reading scale (WRS) and all the TAS scales: the Line Length scale (LL, $r = .16$; $n = 114$; Hommel adjusted p-value $= .977$), the Line Orientation scale (LO, $r = -.04$ $n = 114$; Hommel adjusted p-value $< .977$), Simple Shape identification (SS, $r = .08$; $n = 114$; Hommel adjusted p-value $< .977$), the Spatial Relations scale (SR, $r = .01$; $n = 114$; Hommel adjusted p-value $= .977$), the Mental Rotation scale (MR, $r = -.02$; $n = 114$; Hommel adjusted p-value $< .977$), the Complex Figure identification scale (CF, $r = -.17$; $n = 114$; Hommel adjusted p-value $= .977$), the Mental Construction scale (MC, $r = -.02$; $n = 114$; Hommel adjusted p-value $< .977$), and the Hidden Figure identification scale (HF, $r = .03$; $n = 114$; Hommel adjusted p-value $< .977$).

As regards the Word Writing Scale, the results highlight non-significant associations between the WWS and all the TAS scales: the Line Length scale (LL, $r = -.01$; $n = 114$; Hommel adjusted p-value $= .977$), the Line Orientation scale (LO, $r = -.18$; $n = 114$; Hommel adjusted p-value $= .701$), Simple Shape identification (SS, $r = -.02$; $n = 114$; Hommel adjusted p-value $= .977$), the Spatial Relations scale (SR, $r = -.02$; $n = 114$; Hommel adjusted p-value $< .977$), the Mental Rotation scale (MR, $r = -.003$; $n = 114$; Hommel adjusted p-value $< .977$), the Complex Figure identification scale (CF, $r = -.22$; $n = 114$; Hommel adjusted

Table 2 Pearson's correlation coefficients between the TAS subscales and the criterion measures

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	LL[§]	–												
2	LO	.638 (<.001)	–											
3	SS	.496 (<.001)	.632 (<.001)	–										
4	SR	.620 (<.001)	.700 (<.001)	.724 (<.001)	–									
5	MR	.531 (<.001)	.530 (<.001)	.352 (<.001)	.453 (<.001)	–								
6	CF	.585 (<.001)	.607 (<.001)	.633 (<.001)	0.649 (<.001)	.557 (<.001)	–							
7	MC	.622 (<.001)	.631 (<.001)	.626 (<.001)	.640 (<.001)	.569 (<.001)	.670 (<.001)	–						
8	HF	.628 (<.001)	.664 (<.001)	.492 (<.001)	.583 (<.001)	.705 (<.001)	.657 (<.001)	.699 (<.001)	–					
9	VMI	.458 (<.001)	.463 (<.001)	.362 (<.001)	.549 (<.001)	–	–	–	–	–				
10	CPM	–	–	–	–	.552 (<.001)	.684 (<.001)	.745 (<.001)	.708 (<.001)	–	–			
11	WRS	.156 (=.977)	–.036 (=.977)	.079 (=.977)	.014 (=.977)	–.023 (=.977)	–.169 (=.977)	–.024 (=.977)	.034 (=.977)	–	–	–		
12	WWS	–.008 (=.977)	–.184 (=.701)	–.018 (=.977)	–.019 (=.977)	–.003 (=.977)	–.220 (=.399)	–.148 (=.977)	–.143 (=.977)	–	–	–	–	
13	BGT	–.150 (=.176)	–.248 (=.046)	–.282 (=.032)	–.239 (=.057)	–.108 (=.176)	–.242 (=.052)	–.540 (<.001)	–.344 (=.008)	–	–	–	–	–

[§] LL = Line Length judgment; LO = Line Orientation judgment; SS = Simple Shape identification; SR = Spatial Relations judgment; MR = Mental Rotation; CF = Complex Figure identification; MC = Mental Construction; HF = Hidden Figure identification; VMI = the perception ability subscale of the Visuo Motor Integration Test (VMI; Beery, 1995); CPM = the Raven Colored Progressive Matrices (Raven, 1976); WRS = Words Reading Scale of the Developmental Dyslexia and the Dysorthographia Assessment Battery (Sartori et al., 1995); WWS = Words Writing Scale of the Developmental Dyslexia and the Dysorthographia Assessment Battery (Sartori et al., 1995); BGT = the Bender Gestalt test (Bender, 1938) scored using the Koppitz system (Koppitz, 1975); in parentheses the Hommel corrected *p*-values are reported.

p-value $< .399$), the Mental Construction scale (MC, $r = -.15$; $n = 114$; Hommel adjusted p-value $= .977$), and the Hidden Figure identification scale (HF, $r = -.14$; $n = 114$; Hommel adjusted p-value $= .977$).

Model validity

In order to evaluate the validity of the cognitive drawing model the correlation coefficients between the battery subscales and Bender's test (BGT) score were computed. Results showed a significant association between the specific visuo-spatial abilities and the drawing abilities. In the Preliminary Analysis section the Line Orientation judgment scale (LO; $r = -.25$; $n = 106$, Hommel adjusted p-value $= .046$) and the Simple Shape identification scale (SS; $r = -.28$; $n = 106$, Hommel adjusted p-value $= .032$) were significantly associated with the Bender test, while the Line Length judgment scale (LL; $r = -.15$; $n = 106$, Hommel adjusted p-value $= .176$) and the Spatial Relations judgment scale (SR; $r = -.24$; $n = 106$, Hommel adjusted p-value $= .057$) were not. Among the Central Task Organization scales the Mental Construction scale (MC; $r = -.54$; $n = 106$, Hommel adjusted p-value $< .001$) and the Hidden Figure identification scale (HF; $r = -.34$; $n = 106$, Hommel adjusted p-value $= .008$) were significantly associated with the drawing task, while the Mental Rotation scale (MR; $r = -.11$; $n = 106$, Hommel adjusted p-value $= .176$) and the Complex Figure identification scale (CF; $r = -.24$; $n = 106$, Hommel adjusted p-value $= .052$) were not.

In addition, Fischer's z test with the Hommel correction indicates that drawing ability is mainly associated with the Mental Construction scale (MC) that indicates a Central Organization ability.

DISCUSSION

The aim of this paper was to present and describe the psychometric properties of a new neuropsychological battery (TAS) designed to test children's visuo-spatial abilities implied in drawing tasks. On the basis of our previous work, and clinical experience (Del Giudice et al., 2000a; Grossi et al., 2002), a visuo-spatial battery was developed. In order to prove its reliability and validity the TAS was administered to a sample of 370 children aged between 4 and 11 years, analyzed with a Rasch measurement model, and compared with standardized tests assessing the same and different abilities.

The results of this study provide evidence for the reliability of the subscales included in our battery. The fit values with the considered measurement model and reliability indices suggest that the battery may provide reliable and internally consistent ratings of visuo-spatial abilities.

The application of a Rasch model, which is coherent with item response theory (IRT; Lord & Novick, 1968; Rasch, 1960/1980; van der Linden & Hambleton, 1997), resulted in the identification of misfitting items and in the estimation of the items' location on unidimensional latent traits. This latter feature, which is specific to Rasch's IRT models, allowed us to compare and order items on the latent traits and to evaluate the measurement power of each subscale. In the next steps of the battery standardization these results will be particularly useful in order to identify, and where necessary remove, items that are too similar or that measure the same point on the latent traits. In fact, given the size of the battery and the characteristics of the target population, we think that a shorter version, with the same discriminative power, would be convenient.

With regard to the validity of the battery, results indicate that the Preliminary Task Analysis and the Central Task Organization subscales correlate in the expected direction with the selected criterion measures (respectively VMI and CPM). With regard to the discriminant validity of the battery, results indicate that the Preliminary Task Analysis and the Central Task Organization subscales do not correlate with the selected criterion measures (Word Reading task and Word Writing task).

With regard to the validity of the cognitive drawing model it is important to stress that, in accordance with the literature (Akshoomoff & Stiles, 1995b; Beery, 1995; Cohen et al., 2000; Del Giudice et al., 2000a; Karapetsas & Kantas, 1991), this study confirms the close relation between visuo-spatial and constructional abilities. A better ability in copy drawing tasks is correlated with a greater development of the perceptual and representational visuo-spatial processes. Besides, the correlations indicate that drawing ability is mainly influenced by the representational and mental manipulation processes—the ability to build a mental model assembling different parts of an object—evaluated by the MC scale. These results confirm that the abilities to represent both the overall configuration of the model and some aspects of the parts of the forms are the most involved skills in drawing tasks (Tada & Stiles-Davis, 1989).

What we need to understand in more detail is the extent to which each of the visuo-spatial processes taken into account contributes to the execution of constructional tasks of different kinds (e.g., in the reproduction of two- and three-dimensional objects) and of different complexity (e.g., in the reproduction of simple and complex objects).

In summary, in accordance with the considered cognitive model, the TAS is a reliable and valid tool for the investigation of the children's basic visuo-spatial processes entailed in drawing tasks. This might have theoretical and clinical implications.

From the theoretical point of view, this battery may allow better investigation of the developmental patterns of visuo-spatial components that seem to develop along different progressive courses (see Del Giudice et al., 2000a), and their link to constructional abilities. Morever, the availability of a comprehensive visuo-spatial battery could help to clarify the divergent evidence about the visuo-spatial deficits in different developmental syndromes that can be found in the literature (Edgin & Pennington, 2005; Mitchell & Ropar, 2004; Skottun, 2000; Winner et al., 2001).

From the clinical point of view, a battery that can analytically and reliably evaluate some basic visuo-spatial abilities could serve as a guide to define specific rehabilitative processes in the constructional dyspraxia. Specifically, the TAS could be useful to identify which visuo-spatial processes are impaired, and to define a cognitive profile for both specific and generalized developmental disorders. This claim receives support from the literature showing visuo-spatial impairments in arithmetic learning disabilities (Geary, 2003; Helland & Asbjornsen, 2003;

Rourke & Strang, 1983), developmental dyslexia (Eden et al., 2003; Facoetti, Zorzi, & Cestnick, 2006; Jaskowki & Rusiak, 2005; Ramus, 2003), autism spectrum disorders (Happé, 2005; Shah & Frith, 1993), Williams' syndrome (Eckert, Hu, & Eliez, 2005; Gray et al., 2006), Down's syndrome (Gunn & Jarrold, 2004; Vicari, 2006), and traumatic brain injury (Akshoomoff, Feroleto, Doyle, & Stiles, 2002; Lehnung, Leplow, & Herzog, 2001; Stiles, 2000).

Finally, the proposed battery could be useful to investigate the role of visuo-spatial components in the cognitive fundaments of the "geometric" abilities, which have been less studied compared to the arithmetic ones. In this sense, the TAS could be used as a screening test for children.

The next step of our work will be an abridged but equally reliable version of each subscale, which will be devised in order to reduce the battery administration time.

In conclusion, the TAS may be a valid tool for researchers interested in investigating the development of visuo-spatial abilities and the dependent cognitive models. In addition, it may be useful to investigate the relationship between basic visuo-spatial abilities and the general cognitive abilities.

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