Neurological Sciences (2019) 40:2045–2050
https://doi.org/10.1007/s10072-019-03929-w

ORIGINAL ARTICLE

Normative data of the Rey-Osterrieth Complex Figure for Italian-speaking elementary school children

Massimiliano Conson[1] · Mattia Siciliano[1,2] · Chiara Baiano[1] · Isa Zappullo[1] · Vincenzo Paolo Senese[1] · Gabriella Santangelo[1]

Received: 26 October 2018 / Revised: 4 May 2019 / Accepted: 9 May 2019 / Published online: 20 May 2019

Abstract

The Rey-Osterrieth Complex Figure Test (ROCF) is a widely used neuropsychological test for the evaluation of drawing disorders in different clinical populations, and, in particular, in persons with neurodevelopmental disorders. The aim of the present study is to provide normative data for ROCF copying (ROCF-Direct copy) and drawing from memory (ROCF-Immediate recall) in Italian-speaking children. The sample consisted of 348 children (147 males and 199 females), aged 7–11 years, recruited from elementary schools in Southern Italy. Normative data were gathered from 312 participants fulfilling the inclusion criteria, and estimated centiles were obtained according to the LMS method providing normalized growth centile standards. Results showed a significant effect of age on performance in both tasks, with a steady increase of drawing accuracy, whereas participants' gender and mean level of parental education did not exert any significant effect. Thus, normative data were stratified by age, and percentile scores were provided allowing a practical use of the ROCF for the clinical evaluation of drawing abilities in both typical and atypical children.

Keywords Rey-Osterrieth Complex Figure Test · Drawing disorders · Normative data · Italian-speaking children · Neuropsychological assessment

Introduction

In clinical neuropsychology, evaluation of drawing abilities is a central step of formal assessment since a failure in drawing tasks, such as copying a geometrical figure, can be observed in several clinical populations, both in the adult [1–3] and in the developing brain [4–6].

In literature on drawing and drawing disorders, one of the most used tasks is the Rey-Osterrieth Complex Figure Test (ROCF). The ROCF was first developed by Rey [7] and then standardized by Osterrieth [8] who devised a scoring system to formalize Rey's administration procedure, and also provided normative data on 230 children and 60 adults. From then on, the ROCF became a widely employed neuropsychological test in both clinical and research settings: it is actually used to assess different cognitive abilities such as visuospatial processing, visual memory, problem solving, planning, and visuomotor coordination [9, 10].

Traditionally, the ROCF is a gold standard for assessing constructional apraxia in adult patients with focal brain lesions and neurodegenerative diseases [1–3], but it has also been considered a useful test to evaluate cognitive functioning in childhood and adolescence [8, 11, 12]. The ROCF task usually involves both copying the complex figure and then reproducing it from memory, immediately, following a delay or both. In children, between the ages of six and eight, relevant changes in ROCF copying seem to be related to an improvement in visual perception and organization [6, 11], while by age 9, a reliable production of all parts of the figure can be observed, and changes after that age tend to reflect the increased capacity to plan and organize the reproduction of the figure [13, 14]. For ROCF immediate recall, classical studies showed that more than half of children between the ages of 5

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10072-019-03929-w) contains supplementary material, which is available to authorized users.

✉ Massimiliano Conson
massimiliano.conson@unicampania.it

[1] Developmental Neuropsychology Laboratory, Department of Psychology, University of Campania Luigi Vanvitelli, Viale Ellittico 31, 81100 Caserta, Italy

[2] Department of Medical, Surgical, Neurologic, Metabolic and Aging Sciences, University of Campania Luigi Vanvitelli, Naples, Italy

and 14 were able to reproduce ROCF from memory immediately after copying it; more in general, errors decrease at each age level, such that 5 years old tend to make significantly more errors than older children [15].

The employment of both ROCF tasks is valuable in clinical settings for the neuropsychological examination of developmental disorders. For instance, a poor performance on ROCF copying has been related to intellectual functioning in children with ADHD [16] or to defective visuo-constructional and executive functions [17, 18]; the ROCF drawing from memory performance is significantly associated with visuospatial memory deficits in early unilateral brain injury [19].

While different studies have provided normative data for the ROCF with developmental populations in many Spanish-speaking countries [14, 20] and in US populations [13, 15], no normative data have been published for Italian-speaking children. Indeed, in Italy, normative data are available for the ROCF with adult populations [21–23], but not with pediatric ones.

Here, we aimed at bridging this gap by providing normative data for both ROCF copying and ROCF immediate recall. In particular, we focused on elementary school children since, as recalled above, previous studies showed that children's ability to reproduce the ROCF improves dramatically in this developmental stage [6].

Methods

Participants

Study participants were recruited from elementary schools located in the Campania region, Southern Italy. To be included in the study, each participant had to meet the following inclusion and exclusion criteria: (i) a normal score (> 15th percentile) at the Raven's Colored Progressive Matrices test (CPM) [24, 25]; (ii) age ranging from 7 to 11 years; (iii) lack of neurologic, neuropsychological, or neuropsychiatric disorders, as reported by either parents or teachers; and (iv) Italian as native language.

A sample of 348 children (147 males and 199 females) was recruited for the study, but only 312 (130 males and 182 females; mean age of 9.2 years, SD = 1.2) scored higher than the 15th percentile at the CPM, according to the Italian normative data [24] and satisfied the other inclusion criteria. Prior to testing, informed consent to children's participation was obtained from a parent or legal guardian. The study was approved by the Local Ethic Committee, and performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

ROCF procedure

The original ROCF was used [7] including 18 elements. Scoring followed the classical procedure [8] described in the original manual [26]: 2 points are given when the element is correctly reproduced; 1 point is given when the reproduction is either (i) distorted or (ii) incomplete but placed properly, or (iii) complete but placed poorly; 0.5 point is attributed when the element is distorted or incomplete and placed poorly; a score of 0 is given when the element is absent or is not recognizable. The maximum score for each of the two tasks (copying and immediate recall) is 36.

A trained examiner administered the ROCF copying (ROCF-Direct copy), and after 3 min, the ROCF-Immediate recall was given. To perform the ROCF-Direct copy, the figure was placed in front of the participant, who was required to copy the figure as accurately as possible. When copying the figure was completed, the stimulus was removed from sight. After a 3-min delay, the participant was required to reproduce the figure from memory without forewarning. The delay interval was filled with a distracting conversation between the examiner and the participant. It is worth noting here, that the participant completed the both ROCF tasks using the same black pencil, since the use of colored markers can lead the participants to easy distractibility [10].

Statistical analysis

The overall sample was stratified by age in 8 groups (Table 1); each group encompassed a 6-month age range consistent with previous normative studies (e.g., [27]).

An a priori power analysis for a factorial analysis of variance (factorial ANOVA) was performed with G*Power 3.1 by setting the following parameters: probability level (α), 0.05; statistical power ($1-\beta$), 0.80; moderate effect size (Cohen's f of 0.25); number of groups in the factorial design, 32; numerator degree of freedoms, 7 (i.e., age group levels − 1 × sex factor levels − 1 × mean level of parental education − 1) [28].

Factorial ANOVA was employed to evaluate the effects of age groups, sex, and mean level of parental education on ROCF-Direct copy and on ROCF-Immediate recall. In particular, following Arango-Lasprilla et al. [20], the mean level of parental education (MLPE) variable was obtained splitting the

Table 1 Normative sample stratified by age

Age range (years, months–years, months)	Total
7.0–7.5	29
7.6–7.11	30
8.0–8.5	44
8.6–8.11	29
9.0–9.5	33
9.6–9.11	37
10.0–10.5	53
10.6–10.11	57
Total	312

Table 2 Descriptive statistics stratified by age range are shown as mean (standard deviation)

Age range (years, months–years, months)	7.0–7.5	7.6–7.11	8.0–8.5	8.6–8.11	9.0–9.5	9.6–9.11	10.0–10.5	10.6–10.11	Total
Age, months	87.00 (1.70)	93.03 (1.61)	98.44 (1.82)	104.21 (1.80)	109.98 (1.55)	116.93 (1.48)	122.44 (1.84)	130.10 (3.29)	110.16 (13.93)
Education, years	2.13 (0.34)	2.34 (0.48)	2.70 (0.50)	3.04 (0.20)	3.46 (0.55)	4.24 (0.61)	4.73 (0.48)	4.97 (0.18)	3.62 (1.10)
ROCF-direct copy	24.48 (6.62)	24.07 (6.35)	28.20 (4.87)	29.41 (5.16)	27.39 (5.72)	27.76 (5.70)	30.62 (5.00)	30.32 (4.74)	28.23 (5.81)
ROCF-immediate recall	11.86 (6.36)	11.17 (5.22)	13.05 (6.71)	14.31 (6.45)	15.24 (5.39)	14.70 (6.42)	16.40 (6.83)	16.14 (6.57)	14.44 (6.53)
CPM	23.93 (4.89)	23.77 (4.48)	26.66 (3.80)	27.28 (3.90)	27.18 (4.05)	28.03 (4.94)	29.30 (4.05)	30.56 (3.32)	27.56 (4.64)

ROCF, Rey-Osterrieth Complex Figure Test; *CPM*, Colored Progressive Matrices

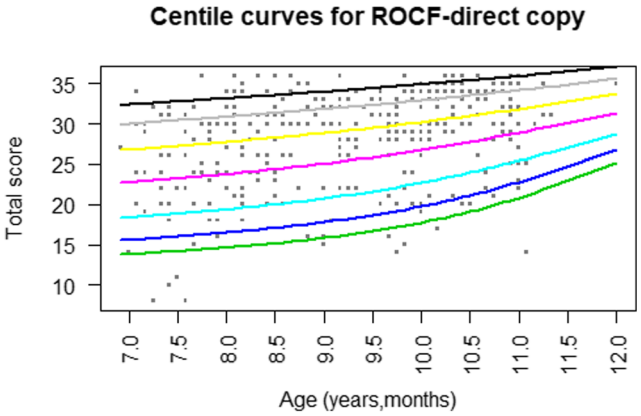

Fig. 1 Estimate of ROCF-Direct copy centiles. Green, blue, light blue, purple, yellow, gray, and black curves represent 3rd, 5th, 10th, 25th, 50th, 75th, and 90th percentile, respectively

sample into two categories: participant's parent(s) with low education (MLPE ≤ 12 years) and participant's parent(s) with high education (MLPE > 12 years). The Bonferroni test was used for post-hoc analysis.

Estimates of ROCF-Direct copy and ROCF-Immediate recall centiles were obtained using the LMS method [29], which provides a way for obtaining normalized growth centile standards. The method assumes that data can be normalized using a power transformation, which stretches one tail of the distribution and shrinks the other. The optimal power (i.e., Box-Cox power transformation) to obtain normality is calculated for each age group and the trend summarized by a smooth (L) curve. Trends in the mean (M) and coefficient of variation (S) are similarly smoothed. The resulting L, M, and S curves contain the information to draw any centile by the following formula:

$$C = M\,(1 + LSZ)^{1/L}$$

where Z is the value of z-score corresponding to centile. The 3rd, 5th, 10th, 15th, 25th, 50th, 75th, 90th, and 97th centiles were chosen as age-specific reference values.

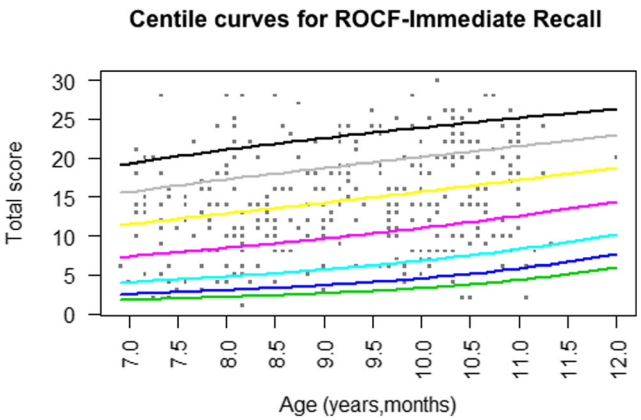

Fig. 2 Estimate of ROCF-Immediate recall centiles. Green, blue, light blue, purple, yellow, gray, and black curves represent 3rd, 5th, 10th, 25th, 50th, 75th, and 90th percentile, respectively

Table 3 Age-specific percentiles of Rey-Osterrieth Complex Figure Test for typical developing children

Age range(years, months–years, months)	L	S	Centiles 3rd	5th	10th	15th	25th	50th (M)	75th	90th	97th
Direct copy											
7.0–7.5	1.53	0.28	8	11	15	17	20	25	29	33	36
7.6–7.11	1.40	0.27	10	12	15	17	20	24	29	32	36
8.0–8.5	1.43	0.17	18	19	22	23	25	28	32	34.5	36
8.6–8.11	2.46	0.17	16	19	22	24	26	30	33	36	36
9.0–9.5	2.29	0.20	11	14	19	21	24	28	32	35	36
9.6–9.11	2.46	0.19	11	15	19	21.5	24	28.5	32	35	36
10.0–10.5	3.44	0.14	13	19	23	25	28	31	34	36	36
10.6–10.11	2.11	0.15	20	21	24	25	27	31	34	36	36
Immediate recall											
7.0–7.5	0.62	0.63	1	2	2	5	7	11	16	21	27
7.6–7.11	0.54	0.51	3	3	5	6	7	10.5	14.5	18.5	23
8.0–8.5	0.59	0.56	2	3	5	6	8	12	17	23	28
8.6–8.11	0.47	0.49	4	5	6	7	9	13	18	23	29
9.0–9.5	0.94	0.39	4	5.5	8	9	11	15	19	23	26
9.6–9.11	0.56	0.46	4	5	7	8	10	14	19	23.5	29
10.0–10.5	0.83	0.46	3	5	7	9	11	16	21	26	31
10.6–10.11	0.80	0.44	4	5	7	9	11	16	21	25.5	30

All analyses were performed using IBM Statistical Package for Social Science (SPSS) version 20, with p value < 0.05 considered as statistically significant.

Results

Descriptive statistics for each age group are reported in Table 2. The a priori power analysis revealed that at least 238 participants (30 for each age group) were needed to attain a moderate effect size.

Factorial ANOVA showed a significant main effect of age group on ROCF-Direct copy ($F = 6.16$, $p < 0.001$, $\eta^2_p = 0.15$), and ROCF-Immediate recall ($F = 3.50$, $p = 0.001$, $\eta^2_p = 0.091$). No further significant main effect or interaction was observed (for details see Supplementary Table 1).

Post-hoc analysis showed statistically significant differences in ROCF-Direct copy scores between 7.0–7.5 and 10.0–10.5 or 10.6–10.11 age group. Similarly, significant differences were found between 7.6–7.11 and 8.0–8.5 or 10.0–10.5 or 10.6–10.11 age group. As for ROCF-Immediate recall scores, significant differences were found between 7.6–7.11 and 10.0–10.5 or 10.6–10.11 age group.

Centile curves [29] for ROCF-Direct copy and ROCF-Immediate recall scores are provided in Figs. 1 and 2, respectively. ROCF-Direct copy and ROCF-Immediate recall centiles are reported in Table 3. When the percentile of interest is not available, it is possible to estimate it by abovementioned

Table 4 Bonferroni post-hoc analyses for Direct copy (above the diagonal) and Immediate recall (below the diagonal)

Age range (years; months–years; months)	7.0–7.5	7.6–7.11	8.0–8.5	8.6–8.11	9.0–9.5	9.6–9.11	10.0–10.5	10.6–10.11
7.0–7.5		1.000	0.124	*0.017*	1.000	0.436	*< 0.001*	*< 0.001*
7.6–7.11	1.000		*0.040*	*0.005*	0.438	0.168	*< 0.001*	*< 0.001*
8.0–8.5	1.000	1.000		1.000	1.000	1.000	0.831	1.000
8.6–8.11	1.000	1.000	1.000		1.000	1.000	1.000	1.000
9.0–9.5	1.000	0.324	1.000	1.000		1.000	0.215	0.403
9.6–9.11	1.000	0.682	1.000	1.000	1.000		0.399	0.735
10.0–10.5	0.062	*0.010*	0.287	1.000	1.000	1.000		1.000
10.6–10.11	0.096	*0.017*	0.445	1.000	1.000	1.000	1.000	

Significant differences are signed in italic

formula and considering the LMS parameters associated to each age group (Table 3). For example, to compute the 95th percentile (corresponding to z-score equal to 1.64) of ROCF-Direct copy for 9.0–9.5 age group, the formula above becomes $28 \times (1 + 2.29 \times 0.20 \times 1.64)^{1/2.29} = 35.76$ which can be approximated to integer score of 36.

Discussion

In the present study, we provided normative data of the ROCF-Direct copy and the ROCF-Immediate recall for Italian-speaking elementary school children, since at the moment, Italian normative data are available for adults only.

Results showed a significant main effect of age on performance on both drawing tasks; in particular, for the ROCF-Direct copy, we found that although performance steadily increased as a function of age, a remarkable improvement was observed when comparing younger children (7 to 7.11) with older ones (10 to 10.11), whereas less relevant differences were found across younger children. These results nicely fit a classical study by Akshoomoff and Stiles [11] who conducted a series of experiments to analyze performance on the ROCF-Direct copy in 6- to 12.8-year-old participants, and in a group of adults. The authors found that the most relevant changes in drawing performance could be detected at about 10 years although a steady increase in different aspects of drawing accuracy and strategy could be observed from 6 years. More recently, Arango-Lasprilla et al. [20] provided normative data of both ROCF-Direct copy and Immediate recall (3 min) on a large sample of children and adolescents from different Latin American countries and Spain. The results showed that age was significantly related to the total score of both ROCF tasks, so that scores increased notably between ages 6 and 13, while the increase slowly reduced after about the ages 13–14. Consistent with these results, here, we found that performance on the ROCF-Immediate recall was significantly affected by age with a trend analogous to that observed for the ROCF-Direct copy. These findings are also in line with those from the Senese et al.'s study [30], which investigated the cognitive predictors of ROCF performance in elementary school children and found that age correlated with both ROCF-Direct copy and Immediate recall, as well as with almost all cognitive measures assessing visuospatial abilities (Table 4).

Besides the participants' age, other variables such as participants' sex and parental education might play a role in ROCF drawing; however, here, we did not find any effect of these parameters on ROCF performance. As for the participants' sex, our results fit with previous findings on children [20, 30] and adults [22, 31], whereas as for parental education, available data are less straightforward. Indeed, while there is some evidence that parents' demographics, such as the socioeconomic status, can influence the developmental trajectory of spatial abilities [32, 33], the relationship between parents' demographics and drawing skills is much less understood. For instance, Levine et al. [34] investigated predictors of preschoolers' spatial transformation skills and found that children who were observed playing with puzzles between 2 and 4 years of age performed better on a spatial task (mental transformations of 2D figures) than those who did not, irrespective from parental education and income. The findings from Arango-Lasprilla et al. [20] were instead more complex since parental education was associated with the ROCF-Direct copy score in Chile, Puerto Rico, and Spain, whereas it was associated with the ROCF-Immediate recall score in Paraguay and Spain, although for both tasks children whose parents had more than 12 years of education scored significantly higher than children whose parents had an education below 12 years.

Taking into account the abovementioned data, in the present study, we explored the effect of socioeconomic status, as indexed by parental education [20, 35], on ROCF performance. Our results showing no effect of parental education on both copying and immediate recall of the ROCF were not fully consistent with Arango-Lasprilla et al.'s [20] data on Spanish-speaking participants, whereas they were in line with Senese et al.'s [30] data on Italian-speaking elementary school children showing that socioeconomic status did not significantly influence ROCF copying and drawing from memory performance.

The results of the present study have useful clinical implications, since we provided normative data for the ROCF in an age range so far unavailable for Italian population. Indeed, established norms for Italian-speaking elementary-school children allow clinical neuropsychologists to use this well-consolidated test as part of their formalized assessment protocols in order to assess visuospatial, visual-motor, and visual memory abilities in children with developmental disorders.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study

References

1. Lezak MD (1995) Neuropsychological assessment, 3rd edn. Oxford University Press, New York
2. Gainotti G, Trojano L (2018) Constructional apraxia. Handb Clin Neurol 151:331–348

3. Trojano L, Conson M (2008) Visuospatial and visuoconstructive deficits. Handb Clin Neurol 88:373–391
4. Mervis CB, Robinson BF, Bertrand J, Morris CA, Klein-Tasman BP, Armstrong SC (2000) The Williams syndrome cognitive profile. Brain Cogn 44:604–628
5. Meyer-Lindenberg A, Kohn P, Mervis CB, Kippenhan JS, Olsen RK, Morris CA, Berman KF (2004) Neural basis of genetically determined visuospatial construction deficit in Williams syndrome. Neuron 43:623–631
6. Stiles J, Akshoomoff N, Haist F (2013) The development of visuospatial processing. In: Rubenstein JLR, Rakic P (eds) Comprehensive developmental neuroscience: neural circuit development and function in the brain, vol 3. Amsterdam, Elsevier, pp 271–296
7. Rey A (1941) L'examen psychologique dans les cas d'encephalopathie traumatique. Arch Psychol 37:126–139
8. Osterrieth PA (1944) Le test de copie d'une figure complexe: contribution a l'étude de la perception et de la memoire. Arch Psychol 30:206–356
9. Meyers J, Meyers K (1995) Rey complex figure test under four different administration procedure. Clin Neuropsychol 9:63–67
10. Shin MS, Park SY, Park SR, Seol SH, Kwon JS (2006) Clinical and empirical applications of the Rey-Osterrieth complex figure test. Nat Protoc 1:892–899
11. Akshoomoff NA, Stiles J (1995) Developmental trends in visuospatial analysis and planning: I. copying a complex figure. Neuropsychology 9:364–377
12. Akshoomoff NA, Stiles J (1995) Developmental trends in visuospatial analysis and planning: II. Memory for a complex figure. Neuropsychology 9:378–389
13. Waber DP, Holmes JM (1985) Assessing children's copy productions of the Rey-Osterrieth complex figure. J Clin Exp Neuropsychol 7:264–280
14. Ardila A, Rosselli M (1994) Development of language, memory, and visuospatial abilities in 5- to 12-year-old children using a neuropsychological battery. Dev Neuropsychol 10:97–120
15. Waber DP, Holmes JM (1986) Assessing children's memory productions of the Rey-Osterrieth complex figure. J Clin Exp Neuropsychol 8:563–580
16. Mahone EM, Hagelthorn KM, Cutting L et al (2002) Effects of IQ on executive function measures in children with ADHD. Child Neuropsychol 8:52–65
17. Del Giudice E, Grossi D, Angelini R et al (2000) Spatial cognition in children. I. Development of drawing-related (visuospatial and constructional) abilities in preschool and early school years. Brain Develop 22:362–367
18. Watanabe K, Ogino T, Nakano K, Hattori J, Kado Y, Sanada S, Ohtsuka Y (2005) The Rey-Osterrieth complex figure as a measure of executive function in children. Brain Develop 27:564–569
19. Akshoomoff NA, Feroleto CC, Doyle RE, Stiles J (2002) The impact of early unilateral brain injury on perceptual organization and visual memory. Neuropsychologia 40:539–561
20. Arango-Lasprilla JC, Rivera D, Ertl MM, Muñoz Mancilla JM, García-Guerrero CE, Rodriguez-Irizarry W, Aguayo Arelis A, Rodríguez-Agudelo Y, Barrios Nevado MD, Vélez-Coto M, Yacelga Ponce TP, Rigabert A, García de la Cadena C, Pohlenz Amador S, Vergara-Moragues E, Soto-Añari M, Peñalver Guia AI, Saracostti Schwartzman M, Ferrer-Cascales R (2017) Rey-Osterrieth complex figure - copy and immediate recall (3 minutes): normative data for Spanish-speaking pediatric populations. NeuroRehabilitation 41:593–603
21. Bertolani L, De Renzi E, Faglioni P (1993) Test di memoria non verbale di impiego diagnostic in clinica: taratura su soggetti normali. Arch Psicol Neurol Psichiatr 54:477–486
22. Caffarra P, Vezzadini G, Dieci F, Zonato F, Venneri A (2002) Rey-Osterrieth complex figure: normative values in an Italian population sample. Neurol Sci 22:443–447
23. Carlesimo GA, Buccione I, Fadda L et al (2002) Standardizzazione di due test di memoria per uso clinico: Breve Racconto e Figura di Rey. Nuova Rivista di Neurologia 12:1–13
24. Pruneti CA, Fenu A, Freschi G et al (1996) Aggiornamento della standardizzazione italiana del test delle Matrici Progressive Colorate di Raven (CPM). Bollettino di Psicologia Applicata 217: 51–57
25. Raven J, Court JH, Raven JC (1998) Raven manual, section 1 (general overview) and section 2 (Coloured progressive matrices). Oxford Psychologist Press, Oxford
26. Rey A (1983) Reattivo della figura complessa. Manuale. Organizzazioni Speciali, Florence
27. Mozzanica F, Salvadorini R, Sai E, Pozzoli R, Maruzzi P, Scarponi L, Barillari MR, Spada E, Ambrogi F, Schindler A (2016) Reliability, validity and normative data of the Italian version of the bus story test. Int J Pediatr Otorhinolaryngol 89:17–24
28. Cohen J (1988) Statistical power analysis for the behavioral sciences, 2nd edn. Lawrence Earlbaum Associates, Hillsdale, NJ
29. Cole TJ, Green PJ (1992) Smoothing reference centile curves: the LMS method and penalized likelihood. Stat Med 11:1305–1319
30. Senese VP, De Lucia N, Conson M (2015) Cognitive predictors of copying and drawing from memory of the Rey-Osterrieth complex figure in 7- to 10-year-old children. Clin Neuropsychol 29:118–132
31. Ponton MO, Satz P, Herrera L, Ortiz F, Urrutia CP, Young R et al (1996) Normative data stratified by age and education for the neuropsychological screening battery for Hispanics (NeSBHIS): initial report. J Internat Neuropsychol Soc 2:96–104
32. Casey BM, Dearing E, Vasilyeva M, Ganley CM, Tine M (2011) Spatial and numerical predictors of measurement performance: the moderating effects of community income and gender. J Educ Psychol 103:296–311
33. Verdine BN, Golinkoff RM, Hirsh-Pasek K, Newcombe NS, Filipowicz AT, Chang A (2014) Deconstructing building blocks: preschoolers' spatial assembly performance relates to early mathematical skills. Child Develop 85:1062–1076
34. Levine SC, Ratliff KR, Huttenlocher J, Cannon J (2012) Early puzzle play: a predictor of preschoolers' spatial transformation skill. Dev Psychol 48:530–542
35. Levine SC, Vasilyeva M, Lourenco SF, Newcombe NS, Huttenlocher J (2005) Socioeconomic status modifies the sex difference in spatial skill. Psychol Sci 16:841–845