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著者	Sanada Satoshi, Kado Yoko, Tsushima Yasuko, Hirasawa Toshimi, Shintani Mai, Nakano Kousuke, Ogino Tatsuya
journal or publication title	Childhood Studies = 子ども学論集
volume	4
page range	1-10
year	2018-03-31
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その他のタイトル	神経心理学的検査を用いて評価した実行機能の発達的側面
URL	http://hdl.handle.net/10112/15894

Developmental considerations of executive function evaluated using neuropsychological examinations.

Satoshi Sanada [1], Yoko Kado [2], Yasuko Tsushima [3],
Toshimi Hirasawa, Mai Shintani [5], Kousuke Nakano [4], Tatsuya Ogino [5]

[1] Faculty of Arts and Sciences, Hiroshima Bunka Gakuen University,
[2] Faculty of Letters, Kansai University,
[3] Faculty of Education, Shujitsu University,
[4] Kurashiki City Kurashiki Support School
[5] Faculty of Education, Ehime University,
[6] Faculty of Children Studies, Chugokugakuen University

Abstract

Children with executive dysfunction may have a decreased quality of life. Neuropsychological tests include the Stroop test, Trail-making Test, Wisconsin Card Sorting Test, Continuous Performance Test, and the Rey-Osterrieth Complex Figure Test are administered to evaluate the above functions. To broaden the opportunities for clinical application, we have modified these tests to make them applicable to younger children and to obtain their standard values. The purpose of this research is to study the developmental aspects of these tests, focusing on the difference between the original method and the modified method. Index scores that reflected executive function were rapidly reduced until 9 to 11 years of age, and developments showed a deceleration during the adolescent period. This result was comparable with that of the index scores of the original tests. We also discussed the involvement of background neuronal maturation associated with developmental changes in these tests.

Keywords: executive function, neuropsychological examination, development, neuronal maturation

Introduction

Executive functions (EF) generally refer to higher-level cognitive functions that are involved in the control and regulation of lower-level cognitive process and goal-directed, future-oriented behavior [1)]. Children with higher-level cognitive dysfunction may, especially in the school environment, show a decline in their quality of life and an increase in maladjusted behavior. Thus, their self-esteem will be significantly affected. To assess the above-mentioned dysfunctions, standard psychometric tests including Wechsler's Intelligence Scale for Children (WISC) and the Binet Intelligence Test are commonly used. However, these tests do not entirely and appropriately describe the cognitive profile. Thus, the neuropsychological tests —Wisconsin Card Sorting Test (WCST), Rey-Osterrieth Complex Figure Test (Rey-CFT), Continuous Performance Test (CPT), Stroop Test and Trail-making Test (TMT) — are expected to appropriately describe the above-mentioned functions.

To broaden the opportunities for clinical application, it is essential to modify these tests so that they are applicable to younger children and to obtain their standard values. In 2004 we started a series of studies [2), 3), 4), 5), 6)] on the neuropsychological tests, which are consistent with the above objectives. From the beginning of our study, we used existing or newly created tests and simplified the procedure so that the tests can be completed by smaller children. For the Keio version of the WCST (KWCST) [7), 8)] and the Conners' Kiddie CPT (K-CPT) [9)], preexisting tests were used, and for the Stroop Test and the TMT we made changes based on the original tests [4), 6)]. For the assessment of Rey-CFT assessment, we used the Boston Qualitative Scoring System (BQSS) [10)]. This enables a more detailed evaluation than the DSS, which is commonly used to evaluate children. We have already reported the standard values of various index scores for the above-mentioned neurological tests from childhood to adolescence and/or adulthood, elsewhere since 2004 [2), 3), 4), 5), 6)]. For developmental aspects, however, we have not compared our results of using modified tests or different evaluation methods sufficiently with those using the original tests or commonly used evaluation methods.

This study, therefore, aims to summarize the functions that could be evaluated by each neuropsychological tests and then to compare the developmental trajectories of the above-mentioned index scores measured using the modified tests, compared to those of the original test. We also discuss the involvement of background neuron maturation associated with developmental changes in these tests.

Methods

Table 1 summarizes the key points on the modification or application of the Stroop Test [4)], TMT [11)], KWCST [7), 8)], KCPT [9)] and Rey-CFT [10)]. For the Stroop Test, we modified the original test by reducing the number of stimuli from the original 100 to 24, and we used Japanese Kana script instead of alphabet letters. For the TMT, we used Japanese Kana script instead of alphabet letters. The Keio version Wisconsin Card Sorting Test (KWCST) was modified from the WCST by Kashima et al [7), 8)] reducing the response card from the original 128 to 48. This test is divided into two steps and brief instruction are given as a hint before the second step. For the CPT, we utilized the KCPT. Conners modified the test from his original version to the KCPT using pictures instead of alphabet letters. For the Rey-CFT, we used the BQSS for the assessment, as described above.

Table 1. Key points on the modification of neuropsychological tests

Neuropsychological test	Modification	Modified version
Stroop Test	utilize four colors reduce number of stimulus from 100 to 24 utilize “Kana” instead of alphabet	Hirasawa et al. (2009)
Trail Making Test	utilize “Kana” instead of alphabet	Kashima et al. (1986)
Keio version Wisconsin card sorting test	Reduce response cards from 128 to 48 The test is divided into two steps, and a brief instruction as a hint is given before second step.	Kashima et al. (1993; 1995)
Kiddie version CPT	Uses illustrations instead of alphabet on the CPT as test stimulus Shortened the administration time from 14 minites into 7.5 minutes.	Conners (2001)
Rey-CFT evaluated by BQSS scoring method	The BQSS method provides numerous comprehensive qualitative scores and quantitative summary scores by assessing visual memory and visuoconstructional ability, and drawing strategies.	Stern et al. (1994)

The following index scores for each test were investigated in this study: Word reading (WR), color naming (CN), and incongruent color naming (ICN) for the Stroop Test; perseverative errors of Nelson (PEN) and difficulty of maintaining set (DMS) for the KWCST; omissions error (OE) and commissions error (CE) for the KCPT; and copy presence and accuracy (CPA), immediate presence and accuracy (IPA), delayed presence and accuracy (DPA), and organization (ORG) for the Rey-CFT. For the TMT, we examined the execution time for Part A and Part B.

Results

1) Target function of the neuropsychological tests

Levin, et al (1991) [12] investigated on the developmental changes in performance on cognitive and memory tests, and in this study, they described the tests that were purported to reflect the frontal lobe function. Before and after this study, many researchers had studied on this issue and now it is generally believed that neuropsychological tests can assess EF. A subclass of the EF and representative study about these functions are summarized in the Table 2. EF subdivision is attention, inhibition, mental flexibility, planning, working memory, visual search and visuospatial organization.

Table 2. Target functions of a neuropsychological test and summary of a comparative study

Neuropsychological test	Function	Outline of the developmental changes in performance		Evaluation of comparison
		Original test / assessment	Modified test / assessment	
Stroop Test	selective attention response inhibition	Although interference score (ICN - CN) showed nonlinear relationship, it declined from around 10 years till 17 years. (Leon-Carrion et al., 2004).	ICN score decreased rapidly from 6 to 11 years of age and decelerated during the adolescent period (Hirasawa et al., 2009).	compatible result
Trail-making Test	visual search working memory mental flexibility divided attention	Performance in Part B showed rapid improvement from 7 to 10 years of age, and then, it decerelated from 10 to 13 years (interpreted from their data) (Anderson 2001).	Part B score shortened rapidly until 11 years of age and decelerated during the adolescent period (Sanada, et al 2012)	indistinguishable result
Wisconsin Card Sorting Test	set-shifting response inhibition working memory concept formation	Improvement trend from 6 to 30s year of age (interpreted from their data) (Heaton et al., 1993).	The first step of PEN score steadily improved until 19 years of age (Kado et al., 2004).	compatible result
Continuous Performance Test	vigilance sustained attention response inhibition	Performance scre of both OE and CE showed stedily improvement until around 10 years and decelerated afterwards (interpreted from their data) (Conners, 2001).	CE score steadily improved until 18 years of age. OE score improved until 10 years of age and remained to the same level (Tsushima et al., 2010).	For OE performance, comparable result. For CE performance, different result; CE showed floor effect around 10 years.
Rey-CFT	visuospatial organization planning working memory	Assessed by DSS, Copy performance showed moderate improvemet from 7 years until 9 years, and *it decererated until* 13 years of age, recall performance showed milder improvement, and organization performance showed slight improvement from 7 to 13 years of age (interpreted from their data) (Anderson, 2001).	Assessed by BQSS, the CPA and recall condition (IPA and DPA) performance steadily improved, and organization performance slightly improved from 6 years until 16 years of age (Nakano et al., 2006).	indistinguishable result

ICN, incongruent color naming; CN, color naming; PEN, perseverative errors of Nelson; OE, omissions error; CE, commissions error; CPA, copy presence and accuracy; IPA, immediate presence and accuracy; DPA, delayed presence and accuracy

2) Developmental aspects

The Figure shows the developmental trajectories of the various index scores in the Stroop Test, TMT, K-CPT, KWCST, and Rey-CFT.

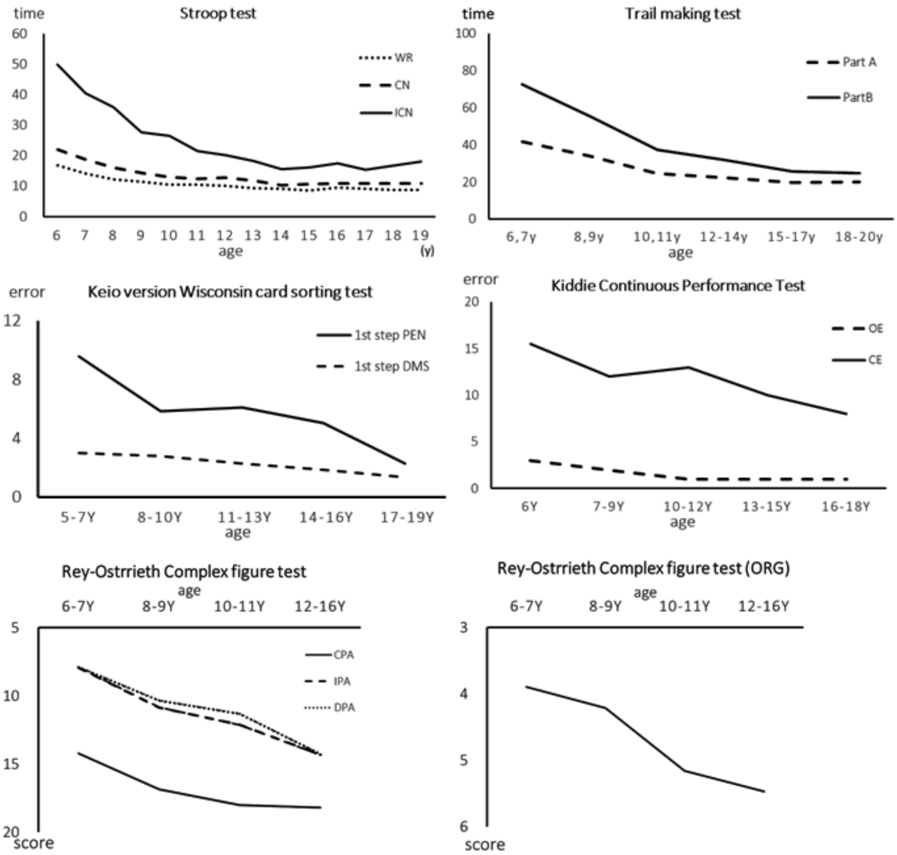

Figure. Developmental trajectories in the neuropsychological tests

In the Stroop Test, developmental trajectory showed the greatest change in ICN scores compared to the other two index scores in those who were 6 to 19 years old. Similarly, for TMT, the trajectory of the part B scores showed a more remarkable change than that of part A scores in the same ages range. For the KWCST, the trajectory of the first step of PEN showed more remarkable change than that of the first step of DMS, and for the KCPT, the OE trajectory was more marked than that of CE. The trajectory of ICN for the Stroop Test, part B scores of the TMT, the first step of the PEN for the KWCST, and OE for the KCPT showed a similar pattern: scores decreased rapidly until 9 to 11 years of age, and developments showed deceleration during the adolescent period. For the Rey-CFT, trajectories of IPA, DPA and ORG scores improved steadily until 16 years of age, while CPA scores improved until 11 years of age.

Table 2 shows the comparison between the development trajectory by the original test and that of the modified test. Additionally, results of the Rey-CFT assessed using DSS were compared to those of our results assessed using BQSS. These results are also shown in Table 2.

Index scores such as Part B of the TMT, first step of PEN for the KWCST, OE of the KCPT, and IPA, DPA, and ORG of the Rey-CFT continuously improved until the end point of our study for 16 to 19-year-olds, and the slope of the development curve ended with downward trend.

Discussion

There were notable differences among the developmental changes in the index scores in the same tests, such as the ICN score vs. CN and WR scores; Part B score vs. Part A score; first step of the PEN score vs. first step of DMS score; OE vs. CE score; DPA, IPA and ORG score vs. CPA score. The second items in each comparison are indices to respond to relatively simple tasks, and EF is presumed to be minimally involved or not involved in the execution of this task; the discrepancy in the results between the former and latter indices might arise from different levels of EF involvement. Because the slope of the development curve of index scores such as Part B of the TMT, first step of PEN for the KWCST, OE of the KCPT, and IPA, DPA and ORG of the Rey-CFT ended with a negative slope, we suggest that the index score strongly related to EF is delayed in completion of maturation and continues until adulthood.

Developmental changes in the latency of visual evoked potential or the auditory brainstem response to evaluate sensory afferent pathways and the special sensory area, and changes in the blink reflex to evaluate the brainstem reflex arc, have been studies, and a critical developmental period was reported to be as early as one month of life to 3 years of age [24]. Holmes (1978) [25] described in his review article, which dealt with the maturation of the central nervous system that elaboration of dendritic and axonal branches, formation of synapses, myelination, and biochemical maturation of neurons and glial cells play a key role in the remarkable changes in EPs with age. Dobbing and Sands (1973) [26] indicated the endpoint of the myelin development as 3 to 4 postnatal years for the whole brain, forebrain, cerebellum and brainstem. Based on this report, it is conceivable that EP development is critically dependent on myelination, but the development of many index scores in neuropsychological tests depends on the subsequent development of structures such as dendrites, and synapses etc. Yakovlev and Lecours (1967) [27], however, described that most major tracts are significantly myelinated by early childhood, and axons within the cortex and in some regions such as the arcuate fasciculus, which is a white matter bundle near the temporal lobe, continue to myelinate into the second and third decades of life, and thus, involvement of myelination for the improvement of the neuropsychological test scores until adulthood could not be ruled out. Additionally, Lenroot and Giedd (2006) [28] reported the significance of remodeling of gray and white matter that continues into the third decade of life which was revealed by their recent MRI studies. As a conclusion, to develop index scores evaluating EF, myelination, dendritic, and axonal branches, formation of synapses, and biochemical maturation of neurons and glial cells, as well as remodeling of gray matter and white matter should also be considered to be important in a supplementary role.

For the applicable age of the test, the OE of the KCPT was thought to be appropriate only for the younger ages because the floor effect was observed at 10 to 12 years of age. Other indices, however, they seemed to be usable without setting restrictions for the applicable age because we recognized developmental changes equivalent to those of the original version.

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邦文要旨

神経心理学的検査を用いて評価した実行機能の発達的側面

眞田　敏、加戸陽子、津島靖子、平澤利美、新谷真似、中野広輔、荻野竜也

実行機能の障害は、子どもの生活の質の低下につながる可能性があるため、Stroop Test、Trail Making Test、Wisconsin Card Sorting Test、Continuous Performance Test、Rey-Osterrieth Complex Figure Test などの神経心理学的検査を用いて同機能を適切に評価することが求められている。 すでに我々は、これら検査の臨床応用の機会を広げるために、低年齢の子どもに適用が可能な短縮版を開発し成果の報告を行ってきた。 本研究は、従来の方法と短縮化された方法との成績の違いに焦点を当て、これらのテストの発達的側面を研究することを目的とした。実行機能を反映した指標のスコアは、9 歳から 11 歳まで急速に減少し、発達は青年期に減速傾向を示した。 この結果は、従来の検査の指数スコアと同等であった。 我々はまた、これらの検査指標における発達的変化と背景に存在するニューロン成熟過程との関連についても考察した。