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METHODS FOR IDENTIFYING COGNITIVELY GIFTED CHILDREN

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Abstract

A small percentage of children shows outstanding cognitive abilities and perform at much higher levels than their same age peers. Psychological science has absorbed knowledge from different spheres such as psychometrics, mathematics, statistics, and psychology to develop methods for identifying cognitively gifted children. The study of intelligence has a long history and has been influenced by social environment, wars, education systems and revolutions. In this paper we focus on two main techniques of identifying cognitively gifted children (a) intelligence testing and (b) domain specific exams called Olympiads (e.g., math and physics). We provide a short historical perspective of the evolution of intelligence testing in Europe and the USA and domain specific Olympiads in Russia. We discuss advantages and limitations of both techniques. Moreover, we highlight that cognitive neuroscientists have been trying to understand the brain mechanisms that may drive cognitive abilities in highly performing children using neuroimaging techniques such as functional magnetic resonance imaging (fMRI). We summarize the knowledge we gained to date from fMRI studies and show that the majority of studies examine mathematically gifted male adolescents with mental rotation tasks. Despite critical advances there is still a lot to be done in understanding the semantic brain-behavior relations in cognitively gifted children.

Keywords: cognitive giftedness, gifted children, giftedness identification, intelligence testing, IQ, domain specific Olympiads, fMRI.

Cognitive abilities improve gradually over childhood and adolescence. A small percentage of children (~5%; Mcclain & Pfeiffer, 2012) however, show exceptional cognitive abilities. These children are often referred to as cognitively gifted. Research on cognitive giftedness parallels that of intelligence and the development of intelligence scales and exams to identify individuals with advanced cognitive abilities. In what follows we present an overview of the beginnings of intelligence testing and the development of Olympiads, domain

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specific exams in Russia. We will discuss the contribution of functional neuroimaging to our knowledge of cognitively gifted individuals and conclude with advantages and limitations of methods of detecting cognitively gifted children.

Intelligence testing

Over the last 200 years or so, intelligence testing has transitioned from select laboratory use to standard psychological practice. This movement, in the 19th century began from work of physicians, psychologists and researches such as Edouard Séguin, Francis Galton, Alferd Binet and Theodore Simon. Edouard Sйguin, born in 1812, was a French physician who worked with individuals with intellectual disabilities. He used form boards for training cognitively impaired children (Boake, 2002). Later his technique was adapted, and used in the Tactual Performance Test by Henry Goddard in the early 20th century. Francis Galton, a British polymath, also had a significant impact on intelligence testing and behavioural genetics. Galton was born in 1822 and his innovations have affected numerous spheres including sociology, anthropology, statistics and psychology. The fact that he was interested in various forms of human abilities gave him an opportunity to work within several fields at once, and, as a result, he became a founder of psychometrics and differential psychology (Peel, 1954). Being an all-around intellectual he considered school as a place made not only for children's education but also as a great place to study children's mental world. He designed experiments and tests aimed to measure, to some extent, senses as well as character and intelligence. This gave an impetus to measure different psychological qualities, which later scientists adopted and extended, such as Cattell (Godin, 2007).

James McKeen Cattell, born in 1860, was an American psychologist who met Galton in England and created his own test for measuring mental processes. During Cattell's guidance, one of his PhD students, Wissler started research on individual mental and physical differences and, later, being interested in mathematical methods in this field, he became the first one to apply Pearson's correlational formula in psychology. Wissler's PhD work challenged Cattell's intelligence tests as his data revealed no correlation between Cattell's tests and academic achievement (Freed & Freed, 1992).

The history of intelligence testing was marked by the work of French psychologists Alfred Binet and Théodore Simon. A 1882 law required compulsory education for children ages 6 to 14 in France. This was revolutionary at the time. Compared to the United States, for example, no general rules existed for schooling and no motivation was offered by the state for children to study better (Schneider, 1992). France established a national system of exams to select children for secondary and universal education. The importance of an educational system in France determined their interest in intelligence testing in the 20th century. Student selection meant identifying not only good students, but also students who were underperforming. This was necessary because underperforming children could be better educated in special schools; this was the field that spearheaded

Binet's research on child intelligence. In 1889 Binet began working in Sorbonne University and in 1896 he finished his first article on the use of intelligence tests. Then he met Thйodore Simon who became his collaborator and in 1905 they presented together the "measuring scale of intelligence", which became known as the Binet–Simon scale.

This first version of the Binet–Simon consisted of 30 short cognitive tests, which could be completed in 40 minutes. The scale identified the "mental age" of a child and had five sections assessing language skills, memory, reasoning, digit span, and psychological judgments. Children's scores improved as a function the age, which showed the validity of the scale. Three years later the scientists modified their test by grouping it into age levels: chronologically from 3 to 13. The new version (called "age scale") was administrated first by giving a child the age-appropriate test and depending on the results, decrease or increase the test level given (Boake, 2002). The last version of the Binet–Simon scale, released in 1911, was extended and was able to assess intelligence in adults. Since Binet and Simon had tested an impressive sample of individuals, they noted that if more than a half of children of a certain age answered a test set correctly, then scores on that test set should be identified as normal performance for that age. Binet–Simon scales became a basis for future intelligence scales. American psychologist Henry Herbert Goddard discovered Binet–Simon's works and was the first to translate them into English, which helped popularize the test. He also started to use the test in his Vineland Training School, a residential center for children with cognitive disorders.

In 1916 Lewis Terman, an American Psychologist, from Stanford University modified the Binet–Simon scale in various ways (Schneider, 1992). Terman adopted the term intelligence quotient (IQ), a concept introduced by William Stern in 1912, instead of the original "mental age" as it represented a composite score. As part of the Binet-Simon scale revision, Terman also added new tests (e.g., arithmetic reasoning items) and named it the "Stanford–Binet Intelligence test". The Stanford–Binet test became a popular method of intelligence testing in the United States.

The Binet–Simon scale was also modified by Robert Yerkes and James Bridget. These American psychologists transformed the year scale into a point scale, calling it the Yerkes–Bridget's Point Scale Examination (Yerkes, 1915). They grouped items with the same content across different ages into content-specific subtests. In other words, the Yerkes-Bridget's Point Scale began from the easiest item and ended with the most difficult in a specific content-domain. This method formed the basis for the Wechsler test (Boake, 2002).

In parallel, at the Chicago Juvenile Psychopathic Institute psychiatrist William Healy and psychologist Grace Fernald criticized intelligence tests for the lack of testing options where language could be a barrier. Language was an issue not only while administrating the tests to children with different language backgrounds but also to those who had problems in school or to deaf children. As a result, Healy and Fernald proposed their own tests, which did not require any special language background.

One of these tests was the Healy Pictorial Completion (Healy, 1914), which required children to fill the empty spaces of pictures with childhood scenes (Boake, 2002). For example, in the picture of a boy throwing something (the gap), a child could place a ball. The main idea was to make the tests free from language and as interesting for children as possible; thus they used pictures as a non-verbal game. This method was named “performance testing”.

A history of intelligence testing entered into a new phase during the World War I when the testing program was introduced in the United States Army that aimed to identify people who were fit for military service. The main tests were called Group Examinations “Alpha” and “Beta” since it became possible to move from individual intelligence scales to examinations in groups based on the Arhur Sinton Otis and Roger Thomas Lennon (Otis–Lennon) method of multiple-choice. These were point-scales, which required one hour to be administered. Verbal structure of testing made designers to create two versions of the test: “Alpha” was used with literate English speakers and “Beta” assessed people with low ability in English. These tests became another important influence to the Wechsler Intelligence scale.

After obtaining a masters degree at Columbia University, American psychologist David Wechsler decided to work at an Army camp scoring the Alpha examination protocols and after graduating from the School of Military Psychology, he became an administrator of individual psychological examinations. This time inspired his future work on creating his own intelligence tests. His communication with famous scientists such as Spearman, Pearson, Piйron and others had a critical impact on his scientific advancements. The Wechsler Intelligence scale had incorporated the strong points of the mentioned approaches to cognitive assessment. Wechsler moved away from quotient scores and separated intelligence into verbal and non-verbal performance. The WISC (Wechsler Intelligence Scale for Children) first published in the first part of the 20th century (Wechsler, 1949) is available in several editions, and is arguably the most popular intelligence scale for children (Reynolds & Keith, 2017).

In the book “IQ Testing 101” a contemporary psychologist Alan Kaufman describes Wechsler as a mentor that had a great impact on his work in testing intelligence (Kaufman, 2009). This collaboration has resulted in Kaufman’s new tests Kaufman Brief Intelligence Test and Kaufman Test of Educational Achievement. Kaufman Brief Intelligence Test is recognized for its incontestable advantages: briefness (only 1 hour is needed) and reliability (0.95–0.97). It is also suitable for testing individuals from 11 years and older, thus it has been well received and obtained large popularity (Siegel et al., 1994. The Kaufman Test of Educational Achievement is distinguished for being able to assess academic achievements of children and youth from 4 to 25 years and offers two options for scoring the test: (a) scoring by hand and, (b) online scoring. Online scoring is particularly important today, as an online platform is more expansive and gives the opportunity to produce analysis of the individual’s strengths and weaknesses (Frame, Vidrine, & Hinojosa, 2016).

Overall, intelligence tests have evolved from rigid one-dimensional assessments to intelligence tests based on age-dependent and content-dependent scales. Although not adhering to the same historical trajectory, the current age- and content- dependent intelligence tests may be compared to domain-specific examinations, which in Russia we call Olympiads.

Olympiads: Domain specific exams

Domain specific Olympiads have a long tradition in Russian public schools. The St. Petersburg Olympiads are the oldest in Russia; the first of them were conducted in 1934 (Karp, 2003). Educators in the former Soviet Union recognized that a strict education system had a negative effect on gifted students who had their own learning pace (Grigorenko & Clinkenbear, 1994). This realization led to the development of special science high schools in the late 1950s — early 1960s that offered advanced courses in mathematics, physics, chemistry and biology (Grigorenko & Clinkenbear, 1994). An all-Russian Olympiad appeared in 1961, and an Olympiad for the entire Soviet Union in 1967 (Karp, 2003). Olympiad competitions broke new ground with the formation of the Ministry of Education in the Soviet Union in 1967. Olympiads held nationwide became an efficient system of identification highly gifted children. Development of this system offered a long-term competitive advantage during the historical conflict of socialism and capitalism, as highly talented people would better contribute to scientific discoveries and in turn improve economic efficiency. Therefore, Olympiads held nationwide were supported by the government and were implemented in the system of education at every level. Since 1968 the Russian team has participated in international Olympiads (Jeltova & Grigorenko, 2005). The strong tradition of domain specific competitions for identifying and supporting talented youth survived various social, political and cultural changes. In recent years, children and their parents are particularly involved in issues of schooling.

Currently there are 24 domain specific Olympiads in Russia. Each Olympiad completion occurs over four levels, at the (a) school-level, (b) city-level, (c) region-level, and (d) nationwide. The basis of this system is the school, covering the widest range of children. The typical method of selecting gifted children for the first stage is through teacher ratings. Although teacher ratings are not related to official scores for the child, the teachers' skills of recognizing giftedness plays a critical role in the detection of cognitively gifted children. All participants who are ranked at the top by the teacher are invited to compete in the following levels. Olympiads qualify children for entering courses of advanced curriculum (Grigorenko & Clinkenbeard, 1994; Karp, 2010). Entering schools of advanced curriculum, however, also occurs when parents successfully advocate to school officials of their child's advance cognitive functioning.

There are two main methods used for teaching gifted children: the enrichment and the acceleration (Ushakov, 2000). In the enrichment program there are special institutes for gifted children that include sections, clubs, and classes with additional intensive classes in different domains (math, physics, chemistry, chess). These institutes usually offer child-driven curriculum options, which allow modifications in favor of the child's interests. Such options provide good motivation and a suitable environment for the development of gifted children. In the acceleration method children who pass the Olympiad exams with high scores can skip ahead some grades in school. As a result, they can finish school sooner as 14 or 15 years olds instead as 17–18 years olds.

Moreover, there are options that provide ephemeral support for gifted children. In other words these institutes provide enrichment programs, but only short-term, often as vacation centers for gifted children. These centers are able to recruit children who are excellent at math or speak different languages. These centers are geared to give a powerful momentum to the development of gifted children, to provide sufficient motivation for learning. Such institute in Russia is the sochisirius.ru program initiated by the Russian President, which allows about 600 students (10–17 years) to enter a monthly program in efforts of early detection and for professional support of gifted children.

Overall, there are various methods for assessing cognitive giftedness based on intelligence tests and domain specific competitions. Physiological and biological processes expressed in the brain inevitably underline performance on these tasks. Functional magnetic resonance imaging (fMRI), for instance, is a non-invasive technique that provides detailed images of the active regions of the living, active brain. Below we summarize the knowledge we gained to date from fMRI studies with cognitively gifted youth.

Evidence from neuroimaging

For the general population, there is a distributed set of areas that predict individual differences in intelligence (Jung & Haier, 2007). Specifically, Jung & Haier reviewed 37 peer-reviewed neuroimaging studies and report functional (i.e., fMRI and positron emission tomography) and structural (i.e., magnetic resonance spectroscopy, diffusion tensor imaging, voxel-based morphometry) indices related to individual differences in intelligence. They proposed a network that included brain areas in the dorsolateral prefrontal cortex (Brodman areas (BAs) 6, 9, 10, 45, 46, 47), the inferior (BAs 39, 40) and superior (BA 7) parietal lobules, and the anterior cingulate gyri (BA 32). This fronto-parietal network, sometimes called the executive network is also activated to mental-attention and working memory tasks (i.e., tasks that require maintaining and manipulating of information in mind; Arsalidou, Pascual Leone, Johnson, Morris, & Taylor, 2013; Owen, McMillan, Laird, & Bullmore, 2005 for meta-analysis; Rottschy et al., 2012 for meta-analysis). In other words intelligence can be routed to core cognitive processes such as mental-attention and working memory.

The majority of fMRI studies examine adults; however, in the last decade we have seen an exponential increase in the number of fMRI studies with children and youth. We identified five fMRI studies, which investigate brain responses in gifted adolescents (O'Boyle, 2005; Lee et al., 2006; Prescott, Gavrilescu, Cunnington, O'Boyle, & Egan, 2010; Desco et al., 2011; Hoppe et al., 2012). All these fMRI studies with gifted children looked at adolescents 13 to 18 years; three of these tested only math-gifted males (O'Boyle, 2005; Prescott et al., 2010; Hoppe et al., 2012) and three studies used mental rotation tasks (O'Boyle, 2005; Prescott et al., 2010; Hoppe et al., 2012).

Gifted and non-gifted teenagers activate similar areas in response to a rotation tasks however they do so more extensively (Hoppe et al., 2012). In the rotation task used by Hoppe and colleagues (2012), participants were prompted to perform four mental rotations of the presented object in the direction indicated by arrows presented sequentially. Active brain areas common to both groups of teenagers included the fronto-parietal network. Compared to their peers, gifted teenagers showed increased activation in the posterior parietal cortex, consistent with findings that investigated gifted teenagers performance on a reasoning task, but was inconsistent with findings that investigated gifted teenagers performance on a planning task (Desco et al., 2011). The results by Hoppe et al. (2012) were also partially consistent with O'Boyle (2005), who showed that gifted teenagers who showed heightened activity in parietal and frontal regions in response to a mental rotation task. Thus, current fMRI studies in the literatures show that it is clear that there is a relation between giftedness and neurocognitive responses, however we cannot specify that relation semantically.

Advantages and limitations of current methods of identifying gifted children

Intelligence testing and Olympiads have survived the test of time, which suggests that they are necessary and useful in various sectors of society. Intelligence scales, for example, provide assessment options with common rules and procedures and validated tests. An advantage of Olympiad exams is that they allow for detecting giftedness in various domains; offering children a chance to shine in a specific domain. Importantly, however there are several limitations of these methods that have been critically reviewed in the literature.

Regarding intelligence testing there are several criticisms: one criticism is the conversion of mental performance into a score, the second is the definition of intelligence, the third is the testing environment and motivation and the fourth is cultural background (e.g. Boake, 2002; Peel, 1954). Converting a cognitive ability to numbers can be the first problem in this area (Boake, 2002; Schneider, 1992). This transformation implies outlining several parts of the construct, which will be test factors, composing scales and statistical processing. Each of these stages limit the cognitive construct, in other words, it does not account for all components of human behavior; usually it is about mathematical and verbal abilities while, for example, Howard Gardner proposed eight types of intelligence (Mohammad, Gholamreza, Hossein, & Mahmoud, 2012).

Similarly, the next issue concerns the understanding of "intelligence". Different authors have different opinions on how many factors intelligence includes or from what values these factors emerge (e.g., Peel, 1954; Boake, 2002). Such opinion differences make the process of creating one universal test impossible. This problem needs either one main theory that most scientists accept or a combination of theories that are consistent.

The test situation, including motivational factors, is critical for intelligence test (Duckworth, Quinn, Lynam, Loeber, & Stouthamer-Loeber, 2011). This problem lies not on theory or tests, but on the participants. In this situation there are at least two factors: (a) the motivation of testers collecting the data and (b) the motivation of individuals who are being tested. The former can affect the results and make a test less reliable, whereas the latter depends on the situational reasons of testing. For example, a person who is tested can be indifferent to scoring well or even fiddle with the results. The issue of motivation is important especially in testing of children who may be unaware of the value of the test if they are young or may not care if they are disaffected youth. Notably, not only low-level motivation can negatively affect test results but also a very high level of motivation, as a nervous person may perform worse.

The last limitation of intelligence tests that is widely discussed is a cultural background. Even though the strength of cultural effects varies, it still has an impact on the results depending on which test is used (Walker, Batchelor, & Shores, 2009). These effects are the most prominent in cultures that are further from Western culture (Ardila & Moreno, 2001), where individuals had psychological trauma (e.g., wars; Steel & Silove, 2001) or have no (or limited) education (Ardila, Rosselli, & Ross, 1989). This area is not yet fully explored but several studies give converging results in performing of representatives of different cultures (Walker et al., 2009). For example, the results of Carstairs's research shows that subjects with English-speaking background performed better on the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Weschsler, 1981) than individuals from a culturally and linguistically diverse background (Carstairs, Myors, Shores, & Fogarty, 2006). At the same time, Reynolds's study illustrates better performance in the same test within white subjects than African American subjects (Reynolds, Chastain, Kaufman, & McLean, 1987). Overall, because intelligence tests mainly rely on culturally biased formal knowledge gained through schooling (e.g., vocabulary, accumulation of facts; Mcclain & Pfeiffer, 2012), they are not culturally fair.

Olympiads as a method of detecting cognitively gifted children, also has some drawbacks. At the first class level, teacher and parental evaluations of a student's performance are susceptible to unconscious biases teachers and parents may have (Bandura, 1993); confirming the common sense expectation that parents tend to overestimate rather than underestimate their child's abilities (Miller, 1986; Miller, Manhal, & Mee, 1991); thus, these ratings are not truly objective. Moreover, with few exceptions of Olympiad exams given at an early age, Olympiad exams are generally taken by students later in adolescents, when students may experience increase interference from motivational and other emotional challenges related to the teenage years. This is important because early schooling is a critical period of optimizing the development of cognitively gifted children and shaping their neuronal connections. Children are born with an abundance of neurons in their brains, significantly more than those of adults (Kolb & Wishaw, 2009). These excessive synaptic connections biologically prime younger children to learn efficiently. Identifying cognitive giftedness early allows for improving education options for these children. This is in line with social constructivist theories that draw on Vygotsky's notion that emphasizes timely intervention for optimal learning (Vygotsky, 1978).

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Резюме

Небольшой процент детей проявляет выдающиеся способности и показывает результаты более высокого уровня, чем их сверстники. Психология как наука собрала знания из разных областей, таких как психометрия, математика, статистика и психология, для разработки методов выявления когнитивно одаренных детей. Изучение интеллекта имело долгую историю, находилось под влиянием социальной среды, а также войн, систем образования и революций. В этой статье мы сосредоточили внимание на двух основных методах выявления когнитивно одаренных детей: (a) тестировании интеллекта и (b) предметных экзаменах, то есть Олимпиадах (например, по математике, физике, биологии и т.д.). Мы представили краткую историческую перспективу эволюции тестирования интеллекта в Европе и США (включая основные методики, их развитие и распространение) и предметных олимпиад в России, а также обсудили преимущества и ограничения обоих методов. Кроме того, мы подчеркнули, что в сфере нейронаук были предприняты попытки понять механизмы, которые могли бы лежать в основе когнитивных способностей у детей, показывающих высокие результаты, с использованием методы нейровизуализации, такие как функциональная магнитно-резонансная томография (фМРТ). Мы собрали и резюмировали знания из фМРТ исследований и показали, что большинство из них рассматривает математически одаренных взрослых мужского пола, используя задание на мысленную ротацию. Несмотря на множество работ и полученных с их помощью данных, многое еще предстоит сделать, чтобы понять семантические взаимоотношения мозга и поведения у когнитивно одаренных детей.

Ключевые слова: когнитивная одаренность, одаренные дети, выявление одаренности, тестирование интеллекта, IQ, предметные олимпиады, фМРТ.

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