REVIEW ARTICLE

CONTENTS

# The influence of heredity and environment on human cognitive ability

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## ABSTRACT

**Aim:** The aim of the study is to consists in the theoretical analysis of the results of modern genetic studies of human cognitive abilities as a key to successful education and upbringing.

**Materials and Methods:** To solve the tasks and achieve the goal of the article, we used general scientific methods of the theoretical level (analysis, synthesis, comparison, systematization, generalization of scientific and theoretical data), regarding the influence of heredity and environment on human cognitive ability.

**Conclusions:** Human cognitive abilities develop under the influence of both genetic and environmental factors. In addition, there is also an active interaction between a person's genotype and his environment, the result of which also affects his cognitive abilities. Different specific cognitive abilities are influenced differently by genes and environment. The regularities of these processes should be known by education leaders, teachers and parents in order to use them in a timely and qualified manner to ensure the most successful education and upbringing of school-aged children.

**KEY WORDS:** heritability, heredity, school performance, common and individual environment, general cognitive ability, specific cognitive ability.

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## INTRODUCTION

The main postulate of genetics is that all characteristics of a living organism are determined by its genes, and are formed under the influence of environmental factors. However, there is another important aspect of an organism's development – the interaction between its genotype and the environment [1]. It is a phenomenon where environmental factors affect different people differently, depending on their gene set, and genetic factors have different effects on a person's characteristics, depending on the characteristics of the environment. These three key principles of genetics carry out the implementation of each characteristic, including the cognitive abilities of a person, which are the determining conditions for education and upbringing. Politicians, teachers, and parents need to know the features of these phenomena to use them in a timely and qualified manner for the successful education of children, especially in primary school, where the foundations of further compulsory school and professional education are laid to ensure achievements in life.

## AIM

The study aims to theoretically analyze the results of modern genetic studies of human cognitive abilities as a key to successful education and upbringing.

## MATERIALS AND METHODS

To solve the tasks and achieve the article's goal, we used general scientific methods of the theoretical level (analysis, synthesis, comparison, systematization, and generalization of scientific and theoretical data), regarding the influence of heredity and environment on human cognitive ability.

The leading role in the work was also played by the interdisciplinary approach, which, within the framework of historical-philosophical research, involves the synthesis of not only the norms of scientific research of primary sources but also theoretical ideas and principles that determine the directions of object research. Also, the interdisciplinary approach played a leading role in the work, which within the scope of the study involves the synthesis of not only the norms of scientific

research of primary sources but also theoretical ideas and principles that determine the directions of the object's research.

## REVIEW AND DISCUSSION

Cognitive abilities, that is, individual differences in properties such as thinking and memory, are one of the oldest and best-studied areas of psychogenetics, or behavioral genetics [2]. Attention to cognitive abilities is partly due to their growing importance in modern human society, where «intellectual capital» is key. In addition, measures of cognitive ability predict major social achievements, such as academic and occupational success, far better than any other [3, 4]. They also predict good health and longevity [5].

Genetic studies of cognitive abilities are based on a hierarchical model of their relationships in which a large number of individual test results on various cognitive abilities are grouped into specific cognitive abilities, which, in turn, make up general cognitive ability [6]. The index of general cognitive ability (g) was proposed by the British psychologist and author of factor analysis Charles Spearman more than a century ago [7]. The term «general cognitive ability» better reflects the essence of the phenomenon than the word «intelligence», since the latter has a large number of different interpretations in psychology and general usage [8].

Intelligence tests, often called IQ (intelligence quotient) tests, are well known. They tend to assess several cognitive abilities together, such as vocabulary, picture completion (pointing out what is missing in a picture), similarity and block building (using colored blocks to create the structure shown in the picture), etc., and give an indicator of general intelligence, or general cognitive ability, or intelligence. In research, general cognitive ability (g) is usually calculated using factor analysis, which takes into account the tests, depending on their contribution to this measure. The contribution of a particular test to g depends on the complexity of the cognitive operations it assesses.

It should also be borne in mind that the existing methods of determining g do not take into account all components of cognitive ability. Thus, the real cognitive ability is greater than the calculated one. As a result, it is better to examine individual cognitive abilities and cognitive skills acquired in the learning process. In addition, cognitive skills play a greater role in achievement than cognitive abilities themselves.

GENERAL COGNITIVE ABILITY

Early studies of human genetics found that parent-child IQ correlations in normal families were greater than in foster families [9, 10]. A later study of families with adopted children showed that the same pattern was observed when comparing adopted children with their biological parents [11]. This proved unequivocally that IQ is genetically influenced. The next major step in the study of the nature of IQ was the so-called Louisville Twin Study, initiated in the early 1960s, which was the first large longitudinal study of IQ [12]. It determined further ways of studying the role of genetic and environmental factors in human intellectual development. At the same time, the special attention of scientists was directed to increasing the volume of experimental samples, increasing the accuracy of measurements and the duration of research.

At the end of the 20th century, it has been conclusively shown that not only IQ but also general cognitive ability g is influenced by genes [1, 13–15]. According to the results of these studies, first-degree relatives who live together are moderately correlated in g (about 0.45). This can be due to both genetic and environmental factors since such relatives are simultaneously affected by both. In families with adopted children, both genetic and environmental factors are shared. The g correlation between adopted children and their biological parents, and between genetically related siblings raised separately, was only. 24. Since relatives of the first degree of consanguinity are only 50% genetically similar, the level of heritability of the indicator g is 0.48 (0.24 x 2), or 48%. This suggests that only about half of the differences between people in g can be accounted for by genes.

A similar pattern is repeated in studies of twins. The average correlation g for monozygotic twins is 0.86 because they are genetically almost identical, and for dizygotic twins, it is 0.60 [8]. The level of heritability g is 0.52, or 52%. Of interest to researchers is the situation when monozygotic twins are raised in different families [1, 15]. Correlation by trait between such twins directly testifies to the level of heritability. According to the results of these studies, the correlation and heritability of g were 0.72 and 0.78, respectively (an average of 0.75, or 75%). This rate of heritability is significantly higher than under other conditions of the experiment.

In the case of an analysis of the combined results of studying all studied situations (within normal families, adopted children, and twin pairs), the heritability g was about 50% [14, 16]. It is noteworthy that the genetic component in this case determines half of the variability of such a complex trait as general cognitive ability. In addition, measurement errors are not taken into account in these studies. If this were done, then the level of heritability would be higher. But, despite this, the genetic influence on g is not only statistically significant but also substantial.

These patterns of inheritance of the g index are observed not only in the population of the countries of Western Europe and North America, where most of the research was conducted. And among the population of Asian countries – Japan and India [8].

Recently, the heritability of traits has been determined using hundreds of thousands of single-nucleotide polymorphisms (SNPs) in the DNA molecules of the entire genome. At the same time, the heritability of g and other behavioral traits is approximately two times lower than in twin studies [17, 18].

If one part of the variability of g can be explained by heredity, then the other part can be explained by the influence of the environment. For example, members of the same family are influenced by common factors of the family environment, as a result of which they partially become similar to each other. Indicators of the influence of the shared environment can be determined based on correlations in the trait between parents and adopted children, as well as between native and adopted children. The g correlation of 0.32 between native and adopted children is particularly impressive. Since they are not genetically related to each other, what makes them similar is nothing more than the shared conditions of existence – the same parents, the same food, studying in the same school, etc. Thus, about a third of the total variability of the trait can be explained by the influence of the common environment. The g correlation between parents and own children turned out to be smaller – 0.19 than between biological and adopted children. This indicates that the shared environment is not perceived the same by parents and their children, in contrast to the perception of it by their own and adopted children [13, 14].

Twin studies also support the presence of shared environmental effects on g. In addition, a shared environment appears to contribute more to the similarity of twins than normal siblings, as the correlation for g even in dizygotic twins (0.60) exceeds that of normal siblings (0.47) [1, 15]. These twins can be more similar to each other than ordinary siblings because their embryos developed in the same conditions and they are the same age. Since they are of the same age, they are most likely to study in the same school, or even in the same class, and be surrounded by the same peers [19].

Calculations have shown that the share of shared environmental influence on g is about 20% for parents and their children, about 25% for siblings, and about 40% for twins [16]. The remaining non-genetic influence is caused by the individual's environment and the presence of possible measurement errors.

## SPECIFIC COGNITIVE ABILITIES

Specific cognitive abilities have been less studied than general, but genetic patterns are similar to those of general cognitive ability [20]. The largest study of specific cognitive abilities was the so-called Hawaii Study of the Process of Cognition, which included more than a thousand families [21]. As in other similar studies, it used the method of factor analysis to identify groups of the most interconnected tests. At the same time, 15 tests were divided into four-factor groups: verbal abilities (including vocabulary and fluency), spatial abilities (visual representation of objects and their rotation in two and three-dimensional space), perception speed (simple calculations and comparison of numbers) and visual memory (recognition of pictures after a short and long period). Parents and their children were significantly similar in all groups of factors, although family similarity was greater in verbal and spatial abilities than in perceptual speed and visual memory.

The generalized results of dozens of early studies of cognitive abilities in twins (Table 1) showed that the heritability of specific cognitive abilities is much smaller than the heritability of general cognitive ability [22]. Word comprehension and perceptual speed were inherited by 40%–50%, and the rest (spatial representations, thinking, fluency, and memory) – on average, by 30% (from 26% in spatial representations to 35% in memory).

The rest of the influence on specific cognitive abilities is provided by the environment – shared and individual. In the above-mentioned studies of twins (table), on specific cognitive abilities, as well as on general, the common environment exerted a moderate influence on different levels – from 14%–18% (memory and speed of perception) to 36%–44% (spatial representations, fluency of speech, understanding of words and thinking). The individual environment also moderately affects specific cognitive abilities, but the levels of influence do not coincide with the levels of influence of the common environment. It mostly affects spatial representations and memory (38% and 51%, respectively). The rest of the abilities are influenced by the individual environment by an average of 30%. The shared environment affects specific cognitive abilities somewhat less on average than general cognitive ability. However, the level of influence of the individual environment on specific cognitive abilities is more than 4 times higher than on general cognitive ability. Such discrepancies regarding the influence of genes and the environment on general and specific cognitive abilities can be explained mainly by the fact that there are still a large number of specific cognitive abilities that have

**Table 1.** The ratio of the influence of heredity and the environment on specific (SCA) and general (GCA) cognitive abilities according to the generalized results of a study of twins (in %)

| Specific cognitive abilities | Heredity | Environment | | Together |
|---|---|---|---|---|
| | | common | individual | |
| Understanding words | 38 | 38 | 24 | 100 |
| Freedom of speech | 29 | 36 | 35 | |
| Thinking | 28 | 44 | 28 | |
| Spatial representations | 26 | 36 | 38 | |
| Perception speed | 50 | 18 | 32 | |
| Memory | 35 | 14 | 51 | |
| Average specific cognitive abilities | 34 | 31 | 35 | |
| General cognitive ability | 52 | 40 | 8 | |

not been identified or have not been taken into account in the research.

Since the content of the individual environment largely depends on a person's choice and personal perception of the common environment, that is, on its hereditary characteristics, it can be assumed that the influence of the individual environment is partially determined by the genes of a specific person.

## SCHOOL PERFORMANCE

At first glance, school tests of students' academic performance differ significantly from tests of specific cognitive abilities. School performance tests focus on program performance in specific academic subjects such as literacy (reading and writing), numeracy (mathematics) and science. Although some subjects, such as history, may seem to be largely about memorizing events and dates, successful study of such subjects requires cognitive skills such as thinking and extracting the essentials from large amounts of information. Other subjects, such as reading and writing, mathematics and science, appear to be more like cognitive abilities because, regardless of content, they are based on general cognitive processes. When it comes to reading, most children in early school age move quickly from learning to read to reading for learning. The difference between literacy numeracy and cognitive abilities is that the first two are subjects that are taught in school, while the general and specific cognitive abilities discussed earlier are not directly taught anywhere, ever. Nevertheless, as will be shown below, multivariate genetic studies reveal significant genetic overlap between academic achievement and cognitive ability.

It is widely believed that success in school is achieved with the help of certain efforts, which are considered components of the environment, while abilities are formed under the influence of genetic factors. As a result, over the past half-century, educational research has focused on environmental factors, such as characteristics of schools, neighborhoods, and parents. At the same time, the possibility of the influence of heredity on children's learning abilities was practically ignored [23).

By far the best studied is reading ability [24]. The results of a long-term study of more than 4,000 twins indicate that processes related to literacy, such as word recognition and reading comprehension, have average heritability rates in a narrow range of 57% to 67%, that is, they are subject to significant genetic influence [25]. Interestingly, the level of heritability of literacy components in the first grades of Australia, Scandinavian countries and the USA is similar and varies around 64% [26]. Similar results were obtained with twins in China, despite the specific orthography of the Chinese language [27].

At first glance, it may seem that the ability to learn to read (recognize words) may be less heritable than reading comprehension, but both processes are highly heritable [28; 29]. Even skills that precede reading (sounding letters and their rapid naming, verbal memory) are significantly influenced by genetics [30, 31]. Studies of the interaction between genotype and environment in twins have shown a decrease in the heritability of reading ability in children from low-income families [32] and an increase in it in children who study with better teachers [33].

As for abilities in other academic subjects of elementary school, even early studies of twins showed their significant heritability and a moderate influence on them in the common environment [34, 35]. Similar results were obtained later in the Netherlands [36], Australia [37] and Great Britain [38]. For example, the results of a study of the performance of British twins of different age groups in English, mathematics and science showed that the heritability of the ability to learn in these subjects varies at the level of 60%, and the influence of the shared

environment at the level of only 20%, even though twins grew up in the same family, attended the same school, and were often taught by the same teachers in the same classroom [38]. Similar results were also obtained in the study of educational achievements at the end of compulsory education at the age of 16 [39].

## CONCLUSIONS

Human cognitive abilities develop under the influence of both genetic and environmental factors. In addition, there is also an active interaction between a person's genotype and his environment, the result of which also affects his cognitive abilities. Different specific cognitive abilities are influenced differently by genes and environment. The regularities of these processes should be known by education leaders, teachers and parents to use them in a timely and qualified manner to ensure the most successful education and upbringing of school-aged children. This is extremely relevant in terms of the modernization of Ukrainian education and bringing it closer to the level of international standards.

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## CONFLICT OF INTEREST

The Authors declare no conflict of interest

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