Giftedness from the perspective of neuroimaging and differential pedagogy. Are we talking about the same thing?

Alta capacidad intelectual desde la neuroimagen y la pedagogía diferencial. ¿Hablamos de lo mismo?

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Abstract:

Advances in neuroimaging techniques have significantly enhanced our ability to study differences in cognitive efficiency in children and adolescents. However, these studies have traditionally used intelligence quotient (IQ) as the sole measure of cognitive ability. Talent development experts are increasingly drawing attention to the major limitations of exclusively using this measure to identify the variables associated with giftedness, in terms of the validity of the construct they intend to measure and in respect of the measurement's reliability and stability. The aim of this study is to analyse whether the construct of intelligence on which recent neuroimaging studies are based, the type of instrument used to quantify giftedness and the corresponding neurobiological results are consistent with the advances made by differential pedagogy in respect of the multidimensional construct of intelligence. To this end, a systematic review both of neuroimaging research that seeks to explain the neural correlates of giftedness in children and adolescents, on the one hand, and of research focussing more prominently on the field of giftedness development, on the other, has been carried out. The findings suggest that brain networks and dynamics associated with creativity and motivation may have a bearing on cognitive performance variability. However, as the majority of neuroimaging studies continue to use IQ as the sole measure of intellectual ability, most of the data produced by these studies cannot be generalised for the purpose of determining what differential pedagogy experts refer to as "giftedness".

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Keywords: giftedness, intelligence, differential pedagogy, neuroimaging, assessment, identification, intelligence quotient.

Resumen:

El avance en las técnicas de neuroimagen ha supuesto una poderosa herramienta para estudiar las diferencias en la eficiencia cognitiva de niños y adolescentes. Sin embargo, tradicionalmente estos estudios han utilizado el cociente intelectual (CI) como única medida de capacidad cognitiva. Cada vez más expertos del desarrollo del talento señalan serias limitaciones en el uso exclusivo de esta medida para identificar las variables que configuran la alta capacidad intelectual (ACI), tanto en cuanto a la validez del constructo que pretende medir como en cuanto a la fiabilidad y estabilidad de la medida. El objetivo de este estudio es analizar si el constructo de inteligencia en el que se basan los estudios de neuroimagen recientes, el tipo de instrumento utilizado para cuantificar la ACI y los resultados neurobiológicos obtenidos son coherentes con los avances hallados por la pedagogía diferencial en cuanto al constructo multidimensional de la inteligencia. Para ello, se ha realizado una revisión sistemática tanto de las investigaciones en neuroimagen que intentan explicar los correlatos neuronales de la ACI en niños y adolescentes como de aquellas investigaciones con mayor relevancia en el ámbito del desarrollo de la ACI. Los hallazgos sugieren que las redes y dinámicas cerebrales asociadas a la creatividad y la motivación podrían influir en la variabilidad del rendimiento cognitivo. Sin embargo, la mayoría de los estudios de neuroimagen continúan utilizando el CI como única medida de capacidad intelectual, por lo que la mayoría de los datos obtenidos a través de estos estudios no pueden generalizarse a lo que los expertos en la pedagogía diferencial denominan ACI.

Descriptores: alta capacidad intelectual, inteligencia, pedagogía diferencial, neuroimagen, evaluación, identificación, cociente intelectual.

1. Introduction

The human brain is designed predominantly to improve efficiency, that is, to minimise the effort involved in processing information and maximise the capacity for growth and adaptation. But why do some people appear to have more efficient brains than others? In recent years, this topic has been extensively researched in the fields of education and neuroscience.

The advances made by genome-wide association studies (GWAS) have revolutionised the research conducted into the genes that regulate variation in intellectual capacity. Moreover, data produced by brain imaging (neuroimaging) techniques have transformed our understanding of the neural correlates of these differences. It has been shown that genetics have no direct bearing on variations in intelligence. Genetics shape phenotypes which in turn affect intelligence

(Goriounova & Mansvelder, 2019). Consequently, neuroimaging techniques have become indispensable to our understanding of the effects of evolution (phylogeny) and development (ontogeny) on learning and intellectual capacity during the life cycle.

In light of recent advances in neuroimaging techniques, paving the way for higher resolution, and of the particular emphasis placed on paediatric populations, short- and long-range structural and functional connections have been established with a view to understanding typical and atypical brain maturation. These studies have shown that neural efficiency is linked to certain quantitative and qualitative characteristics of the neural network, such as a greater density of grey and white matter, an advanced maturation rate, an extended myelination period, greater structural and functional interconnectivity and a greater degree of inter-hemispheric activation (Gómez-León, 2020d; Goriounova & Mansvelder, 2019). These characteristics have been linked to differences in intellectual functioning, such as increased processing speed, reduced energy consumption, greater executive efficiency, and a proficiency in analogical, abstract and creative thinking (Gómez-León, 2019, 2020c; Sastre-Riba & Ortiz, 2018). One conclusion consistently drawn from network neuroscience theory is that functional and structural brain networks with higher global efficiency are associated with higher scores in general intelligence assessments both in children and adults (Barbey, 2018).

This research has traditionally focussed on psychometric intelligence quotient (IQ) tests to measure intelligence, whether they involve a single-factor model such as Raven's test, or a multi-factor model such as the Wechsler Scales (Barbey, 2018; Sastre-Riba & Castelló, 2017). IQ tests measure convergent thinking based on the selection of a single correct answer, unlike tasks designed to assess divergent thinking in which the child is able to provide a solution to a problem via a free-flowing, intuitive or creative approach.

There is quite a broad consensus that intelligence represents not one, but a group of abilities and skills upon which one draws to think rationally, plan, understand complex ideas, learn quickly, solve problems effectively and adapt to the environment (Castelló, 2008; Sternberg, 2012). The capacity to create and innovate is one of the key skills that human beings need to adapt, thrive in rapidly changing environments, undertake complex tasks and make high-quality decisions. Gifted children and adolescents not only perceive complex relationships, form concepts more quickly and store data more efficiently, but they also fare better in solving problems they have not previously encountered and manipulate information more creatively (Gómez-León, 2020b). They exhibit creative aspects of intelligence as well as a greater capacity for fluid reasoning, working memory and mental imagery (Gómez-León, 2020b; Jiménez et al., 2008). That is why talent development experts point out that giftedness is not merely a cognitive phenomenon that can be measured by conventional tools such as IQ tests. They take the view that it also requires the integration of different cognitive and emotional resources which promote learning at an earlier age, different kinds of reasoning and the generation of useful and original ideas (Pfeiffer, 2020; Renzulli, 2021).

Some authors make the distinction between academic abilities related to IQ and productive/creative skills related to inductive reasoning and creative problem-solving (Renzulli, 2021). The predominance of some over others may result in different gifted profiles with distinctive cognitive and behavioural characteristics. While there is no single intellectual profile that is able to define individuals with a greater capacity to adapt successfully to the environment, as a profile increases in complexity, i.e., it presents both convergent and divergent characteristics, the response that a subject is able to deliver to a problem is more effective (Sastre-Riba & Ortiz, 2018). Efficiency in this respect depends both on the amount of stored information and on the number of available intellectual resources and the capacity to manage them (Castelló, 2008; Renzulli, 2021).

Some of the most relevant authors from the field of giftedness (Renzulli, 2021; Sastre-Riba & Castelló, 2017; Tourón, 2020) posit that the use of IQ as a sole measure of intelligence means that:

- The corresponding results are only applicable to some of the aptitudes that give rise to intelligent behaviour, but not all and possibly not to the most relevant ones;
- It is not possible to link the results to the differential complexity of the intellectual profiles of giftedness.
- The samples of gifted children and adolescents may be distorted by false positives and false negatives.

The aim of this study is to analyse whether the construct of intelligence on which recent neuroimaging studies are based, the type of instrument used to quantify giftedness and the corresponding neurobiological results are consistent with the advances made by differential pedagogy in respect of the multidimensional construct of intelligence.

To this end, the studies examining the neural correlates of substantial cognitive ability in children and adolescents are comprehensively reviewed. The following particular aspects shall be assessed: 1) the concept of intelligence defended by the authors; 2) the kind of instrument used to measure intellectual capacity, or intelligence; 3) any cut-off point used to determine giftedness; 4) the brain areas under consideration; 5) the results and the potential scope to generalise them among the gifted population.

The validity of the results produced by neuroimaging studies is addressed on the basis of a comparison with arguments proposed by some of the authors of the most up-to-date intelligence models who are broadly supported by research and the scientific community (Gagné, 2015; Pfeiffer, 2020; Renzulli, 2021; Sastre-Riba & Castelló, 2017; Tourón, 2020).

2. Methodology

Neuroimaging studies linking neurobiological variables to the cognitive ability of subjects were systematically reviewed in accordance with the criteria of the PRISMA statement. To search for these studies, the following terms were entered into the search menus of Pubmed, Scopus, Web of Science and Google Scholar without any language restrictions: gifted* OR talent OR "high ability" OR "high intellectual ability" OR "intelligence" OR "IQ"; AND "neuro*" OR "MRI" OR "brain networks" OR "structural connectivity" OR "functional connectivity" OR "morphometry" OR "DTI" OR "functional magnetic resonance imaging"; AND "development" OR "children" OR "adolescents". The search identified a total of 688 scientific articles.

For the purpose of applying inclusion and exclusion criteria, database entries were imported into the Rayyan QCRI tool (Ouzzani et al., 2016). Duplicates were deleted and a preliminary analysis was carried out on the basis of the abstract sections of the articles. Since the aim of this study was to analyse the construct of intelligence used by these authors, any research focussing exclusively on one or more cognitive skills were excluded as they did not address the global cognitive ability or intelligence of the subjects. After also excluding studies that did not meet the inclusion criteria set out in Table 1, a total of 124 articles remained.

A classification system was established on the basis of the Airtable database in order to extract specific information: author and year; size of sample and sex; age range, mean and standard deviation; intelligence test, analysed IQ interval and cut-off point; principal findings; and brain parameter under examination. After reviewing all the articles, those that failed to meet the inclusion criteria were excluded. As a result, the remaining 24 articles were analysed in depth.

TABLE 1. Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Years of publication: 2010–2021	Year of publication occurring outside of period between 2010-2021
Use of neuroimaging techniques	Review articles and case studies
Samples of children and adolescents	Focussing exclusively on adults
Linking structural and functional characteristics of the brain to global cognitive ability	Linking structural and functional characteristics of the brain to one or more specific cognitive skills (not defined as global cognitive ability)
Assessing scores above population mean or any from the upper portion of the scale	Only analysing scores under the population mean.
The sample does not present any medical or psychological condition that may affect the development of the nervous system.	The selected samples present a medical or psychological condition that may affect the development of the nervous system.

Source: Own elaboration.

A subsequent search was performed to identify the most relevant authors from the field of giftedness development. The Dialnet and Eric databases were added for this purpose. The terms used in this search were "gifted*" OR "talent" OR "high ability" OR "high intellectual capacity"; AND "identification" OR "Diagnosis" OR "development". It included articles published within the past 4 years of the systematic review that meet the eligibility criteria of this research. After the articles were comprehensively reviewed, indirect searches were carried out to identify the most widely cited authors or those whose data are deemed to be relevant or original for the study.

3. Results

The characteristics of the sample (number, sex and age) are specified for the purpose of determining the cognitive construct to which the neural correlates found in the selected studies refer. Moreover, the type of instrument used to measure intellectual ability and the point at which the term "Giftedness" begins to apply are also established.

Magnetic resonance imaging makes it possible to study the neural correlates of cognitive ability via different imaging methods. The corresponding data have been arranged according to the method adopted by the author: structural resonance imaging (Table 2); diffusion tensor imaging (Table 3); and functional MRI and properties of the neural network via graph-theoretic approaches (Table 4).

One of the principal assumptions which sought to link brain characteristics to cognitive ability was that brain volume may be associated with intelligence. It is now feasible to examine the relationship between the morphology of various types of brain tissue and anatomic regions, on the one hand, and cognitive ability, on the other (Table 2).

White matter consists of myelinated axons which transfer information from one region of the brain to another. It makes up around half of the human brain and plays an essential role as primary conductor of nerve signals and also regulates cognitive function. Diffusion tensor imaging has made it possible to measure the properties of the micro-structure of the brain's white matter tracts, such as fractional anisotropy (FA).

The networks analysis describes the brain as a set of nodes, or regions of the brain, that are linked via white matter connections (Barbey, 2018). The brain's functional connectivity data, obtained during rest or task conditions, have been used to assess the functional efficiency of the brain network in relation to cognitive ability (Table 4).

While numerous big data studies have been produced in the past decade around the world to assess the function and structure of the developing human brain on the basis of magnetic resonance imaging, they have not been included because the reviewed samples failed to meet one or more of the inclusion criteria of this study.

TABLE 2. Studies examining relationships between brain morphometry and cognitive ability during development.

First author Year of publication	Sample number (N) Sex: Male (M); Female (F)	Age range, and Mean ± SD	Intelligence test IQ interval Cut-off point	Main results	Brain parameter
Burgaleta et al. (2014a)	N= 188 (78 H, 110 M)	6 - 20 11.59 years ± 3.46	WASI C.I:99.1 -125.34	Links between changes in IQ measurements and changes in cortical thickness, predominantly in left frontal regions.	Cortical surface area, cortical thickness
Fjell et al. (2015)	N= 204 (98 H, 106 M)	8-20 14.8 ± 3.6	WASI C.I: 98.3-119.7	The heterogeneous expansion of the cortical surface area correlates positively with intellectual capacities.	Cortical surface area
Karama et al. (2011)	N= 207 (92 H, 115 M)	6–18.3 11.8 ± 3.5	WASI, WJPEB-III C.I:99-123	Cortical thickness correlates with specific cognitive performance after taking into account the general intelligence factor.	Cortical thickness
Khundrakpam et al. (2017)	N= 586 (141 H, 165 M)	6–18	WASI Low IQ:92-108 High IQ:113-129	The High IQ group has a thicker cortex, not least in the occipital, temporary and limbic cortex.	Cortical thickness
Lange et al. (2010)	N= 285 (130 H, 155 M)	4.10 ± 18.4 10.9 ± 0.21	WASI GCA < 6 años CI:74-144	Positive correlation between volumes of temporal grey matter, temporal white matter and frontal white matter, on the one hand, and IQ, on the other.	Total and regional brain volume
MacDonald et al. (2014)	N= 303 (142 H, 161 M)	6–18,3 11.4 ± 3.5	WASI C.I: 98.7-123.4	Positive correlation between intelligence and striatal volume.	Striatal volume

Margolis et al. (2013)	N= 76 (39 H, 37M)	5-18 10.5 ± 0.5	WASI, WISC-III C.I:80-150	Correlation between cortical thickness in the anterior and posterior regions and the verbal and performance IQ discrepancy.	Cortical thickness
Menary et al. (2013)	N= 181 (81 H, 100 M)	9-24 16.31 ± 3.99	WASI C.I:80-148	Links between cortical thickness and general intelligence in children, adolescents and young adults.	Cortical thickness
Navas-Sánchez et al. (2016)	Mathematically gifted: N= 13 (8 M, 5 F) Control: N= 17 (11 M, 6 F)	Mathematically gifted: 12–14 Control: 11-15 years	WISC Gifted: IQ:112-149 Control: IQ:112-137 Selection criterion: Mathematically gifted group: ESTALMAT	Mathematically gifted adolescents have a thinner cortex and a larger surface area in key regions of frontoparietal networks and on a predetermined basis.	Cortical thickness and surface area
Schnack et al. (2015)	N= 504 (282 H, 222 M)	9–60	WAIS III, WISC-III C.I:80-140	The relationship between cortical thickness and cortical surface area, on the one hand, and intelligence during development, on the other.	Cortical thickness, cortical surface area
Westerhausen et al. (2017)	N= 495 (245 H, 250 M)	6,4-21.9	WASI	Positive correlation between corpus callosum morphology and intelligence.	Corpus callosum

WAIS: Wechsler Adult Intelligence Scale; WASI: Wechsler Abbreviated Scale of Intelligence; WISC: Wechsler Intelligence Scale for Children; WJPEB-III: Psycho-Educational Battery; GCA: General conceptual ability of the differential ability scale; ESTALMAT: visuospatial thinking, intuition, creativity, abstraction, manipulation and management of cognitive stimuli.

Source: Own elaboration.

TABLE 3. Studies examining relationships between the properties of the brain's white matter and cognitive ability during development.

First author Year of publication	Sample number (N) Sex: Male (M); Female (F)	Age range, and Mean ± SD	Intelligence test IQ interval Cut-off point	Main results	Brain parameter
Clayden et al. (2012)	N= 59 (25 H, 34 M)	8-16 11.5 ± 2.1	WISC-IV CI:88-137	Structural changes in FA are a predictor of full scale IQ.	The entire brain.
Kocevar et al. (2019)	N= 43 (32 H, 11 M)	8-12 9.82 ± 1,06	WISC-IV	High IQ associated with greater integrity and density of white matter in the main intra- and inter-hemispheric fibre bundles and well-balanced network organisation between local and global scales.	The entire brain
Koenis et al. (2018)	N= 330 (158 H, 172M)	9-22.9 13.45 años	WISC-III WASI. III C.I:86.4-117	Genetic correlation between IQ and global and local efficiency increased with age.	The entire brain
Navas-Sánchez et al. (2014)	Mathematically gifted: N= 13 (8 M, 5 F) Control: N= 23 (19 M, 4 F)	Mathematically gifted: 12–14 13.8 ± 0.6 Control: 12-15 years 13.4 ± 0.8	WISC Gifted: IQ:112-149 Control: IQ:112-137 Giftedness selection criterion: ESTALMAT	IQ shows considerable positive correlation with the micro-structure of white matter, predominantly in corpus callosum.	Medial orbitofrontal cortex. Rostral anterior cingulate cortex

Nusbaum et al. (2017)	N= 44 (36 H, 8 M)	6,01 - 20,01 11,59 años ± 3.46	WISC-IV ACI CI: ≥ 130 Control CI: 96.4 – 114	Greater integrity of inter- and intra-hemispherical white matter in gifted children.	The entire brain.
Tames et al. (2011)	N= 168 (81 H, 87 M)	8-12 17.7 ± 6.1	WISC-IV CI:82-141	Negative and positive relationships between cortical thickness and volume of white matter, respectively, and IQ.	64 cortical and sub-cortical regions.
Wang et al. (2012)	N= 16 (8 H, 8 M)	13–18 15,3 ± 1,24 16.26 ± 1.3	WASI CI:106.8-125.46	Considerable positive correlation between FA and full scale IQ.	The entire brain.
Westerhausen et al. (2017)	N= 109 (54 H, 55 M)	8-20 17.7 ± 6.1	WASI CI:96.3-118.5	Changes in white matter during life cycle manifest themselves via a dynamic pattern of neurobiological and environmental interactions.	The entire brain.

WAIS: Wechsler Adult Intelligence Scale; WASI: Wechsler Abbreviated Scale of Intelligence; WISC: Wechsler Intelligence Scale for Children; ESTALMAT: visuospatial thinking, intuition, creativity, abstraction, manipulation and management of cognitive stimuli.

Source: Own elaboration.

TABLE 4. Studies examining relationships between functional connectivity or global and local efficiency of the connectome and cognitive ability during development.

First author Year of publication	Sample number (N) Sex: Male (M); Female (F)	Age range, and Mean ± SD	Intelligence test IQ interval Cut-off point	Main results	Brain parameter
Bathelt et al. (2019)	N= 63 (34 H, 29 M)	7–12	WASI (Fluid reasoning) AWMA	The efficiency of the white matter connectome is closely related to IQ and level of education.	The entire brain.
Kim et al. (2016)	N= 99 (54 H, 45 M)	6-11 7.8 ± 1.22	WISC-IV (Perceptual Reasoning)	Positive association between global and local efficiency and visuospatial motor processing.	The entire brain
Langeslag et al. (2013)	N= 115 (56 H, 59 M)	6-8	Snijders-Oomen Niet-verbal- R Subtest: Mosaics, Categories	Association between non-verbal intelligence and parieto-frontal functional connectivity.	The entire brain
Solé-Casals et al. (2019)	N= 29	12.03 ± 0.54	WISC EFAI CI ACI:148.80±2.93 Control:122.71 ± 3.89	High IQ associated with a more integrated (less segregated) neural network and greater inter-modular communication.	Cortical grey matter
Suprano et al. (2019)	N= 58 (44 H, 14 M)	8-12 10.1 ± 1.2	WISC-IV CI ACI 130	Greater efficiency and neural transmission in the giftedness group.	The entire brain

WAIS: Wechsler Adult Intelligence Scale; WASI: Wechsler Abbreviated Scale of Intelligence; WISC: Wechsler Intelligence Scale for Children; AWMA: Working memory assessment: digit recall task, backwards digit recall test, dot matrix and Mister X task; EFAI: Factorial Evaluation of Intellectual Abilities.

Source: Own elaboration.

4. Discussion

4.1. Sample analysis

Despite advances in the exploration methods by which initial stages of brain development are studied, these methods have rarely been applied to developing populations, especially during early childhood at an age when substantial cognitive changes take place. The samples of all the studies under analysis exceed the ages of 4 years and 10 months. The drawback of working with younger subjects predominantly concerns the anxiety that these children will feel as they undergo the MRI, which may make them less cooperative. Moreover, the limited attention span and low accuracy in respect of task performance, coupled with excessive head movement, may potentially undermine the quality of the data and ultimately hinder effective interpretation.

Research shows that, from the age of 4, exposure to favourable or unfavourable environments, or a focus on some domains at the expense of others, has the greatest influence on cognitive and creative development (Gómez-León, 2020c). That is why there is a growing consensus that skills associated with gifted individuals start, peak and end their trajectories at different stages depending on the particular domain in which they develop (e.g., mathematics, creative writing, etc.) (Pfeiffer, 2020). However, the study produced by Navas-Sánchez et al. (2014) is the only research to consider the particular domain in which skills are developed.

On the other hand, according to the study carried out by Schnack et al. (2015), the results corroborate and complement other longitudinal research studies which show that the pattern of cortical maturation in children with high IQ scores is atypical. For instance, the cortical development of children with a high IQ accelerates between the ages of 11 and 12.5 and slows down between the ages of 12.5 and 14. On the other hand, the cortex of children with an average IQ develops slowly between the ages of 11 and 12.5 and speeds up between the ages of 12.5 and 14 (Gómez-León, 2020d). This piece of data is particularly important when cross-sectional samples are studied, as measurements only provide a general insight into changes expected during development. However, of all the studies consulted, not one takes into consideration the differences in the pattern of maturation of the samples.

4.2. Construct of intelligence

Save for the study produced by Navas-Sánchez et al. (2014), all research studies adopt a monolithic approach to measure intelligence via IQ tests. These scales are based on Spearman's factor model whereby performance in mental capacity assessments jointly reflects a specific factor, *s*, which is unique to every test, and a general factor, *g*, which is common to all tests. In terms of general skill level, individuals who fare well in one domain also tend to perform well in others, which is referred to as positive variety. The authors of the studies under review justify the validity and relevance of this instrument as the sole measure of intelligence, by contending that scores: are highly correlated and generate a strong general factor that underlies different abilities; are stable over time; are characterised by high heritability; and predict major life outcomes (Goriounova & Mansvelder, 2019).

However, some authors have analysed whether differences in average IQ between groups with different academic levels can be attributed to *g*, based on the finding that there is no significant association between the scientific construct of general intelligence (*g*) and the differences in intelligence in general (IQ) assessed under WAIS-III (Wechsler Adult Intelligence Scale) (Colom et al., 2002).

On the other hand, scientific evidence has shown that cognitive ability is subject to highly dynamic processes governed by neuronal activity. The structure and functionality of the regions of the brain associated with IQ change during childhood and adulthood and are shaped by learning, hormonal differences, experience and age (Gómez-León, 2020c; Goriounova & Mansvelder, 2019), which is why IQ scores may also change significantly during the life cycle. The Study of Normal Brain Development (NIH) revealed that the scores recorded by 25% of participants between the ages of 6 and 18 in tests-retests taken at an interval of 2 years were marked by differences of 9 points or more (almost 2/3 standard deviation) (Waber et al., 2012). Moreover, the number of hours devoted to practice is a predictor of the level of success achieved in various domains (Pfeiffer, 2020)

In respect of heritability, genome-wide association studies show that intelligence is a highly polygenic trait where genetic variants can only predict between 20% and 21% of IQ variance, less than half of heritability estimates in studies of twins (> 50%), and 0.022% of variance when it is associated with academic achievements as a phenotype of intelligence (Goriounova & Mansvelder, 2019). Consequently, genetic effects on cognitive ability do not materialise independently of environmental factors, but are revealed via transcriptional regulation by signals promoted by experience. As such, some data show that socio-economic status modifies the heritability of IQ in young children (Turkheimer et al., 2003) and that the education of parents has a strong bearing on the IQ of children, without being affected by total or regional brain volumes (Lange et al., 2010).

Moreover, there is growing body of evidence to suggest that IQ scores are not an effective predictor of academic achievements and success in life (Sastre-Riba & Castelló, 2017). In Spain, statistics show that 70% of gifted pupils underachieve at school and between 35-50% fail (Nolla et al., 2017). On the labour market, employees who have achieved a satisfactory academic level do not always reach a professional status that reflects their IQ (Sugiarti et al., 2018). Some authors have taken the view that the selection of individuals based on their high IQ gives them access to a greater number of resources, which facilitates the development of intellectual capacities and enables them to perform better at work (Byington & Felps, 2010), this would be an alternative explanation to the prevailing statement that professional performance is facilitated by IQ in and of itself. More recently, according to the data of the Adolescent Brain Cognitive Development (ABCD), one of the leading neuroimaging studies involving adolescents shows that socio-economic status has a bearing on cognitive development (Sripada et al., 2021), and not necessarily the inverse.

Current talent development models are distancing themselves from this reductionist, static and immutable vision of intelligence and now consider it to be a dynamic, ecological, transactional and developmental status (Renzulli, 2021; Tourón, 2020). From this perspective, every development stage is affected by variables such as available resources, opportunities presented and exploited, social and emotional support system, personal choices, certain personality traits, unforeseen events and even good fortune. This set of variables is thought to determine the score of IQ tests and, ultimately, life success (Pfeiffer, 2020).

4.3. Measurement instrument

All the research papers examined under this study have used different Wechsler scales, save for the research of Langeslag et al. (2013), which was based on the Snijders-Oomen (SON) non-verbal intelligence test. In total, 37% of the research papers have used the Wechsler Intelligence Scale for Children (WISC). This scale is designed to estimate Spearman's *g* factor, according to which a full IQ scale is not regarded as a unitary and interpretable construct unless there is a standard deviation of 1.5 in composite scores (23 points) (Silverman & Gilman, 2020). While this scale is one of the most commonly used to measure IQ, gifted children tend to achieve average/high scores in abstract reasoning tasks (verbal, visuospatial, and fluid reasoning) and lower scores in working memory and processing speed tasks. Discrepancies between these scores may be so significant that the results are not able to be interpreted. As such, according to the recommendation of the National Association for Gifted Children (NAGC), the General Ability Index should be ascertained by performing 6 Verbal Comprehension and Perceptual Reasoning tests broadly related to the abstract reasoning skill which represents the most effective measure of giftedness.

In total, 54% of the studies under assessment used the abbreviated version of Wechsler WASI *(Wechsler Abbreviated Scale of Intelligence)* with 4 sub-tests (similarities*, vocabulary, matrix reasoning, block design)*. This shortened form has been used to produce a quick and reliable assessment of intellectual ability. WASI is underpinned by a number of sub-tests which assess high-level cognitive skills such as verbal comprehension and perceptual reasoning. While these tests have proven to be broadly efficient in the field of giftedness (Aubry & Bourdin, 2018), the position statement of WISC IV and V of NAGC advises that some variables may reduce IQ scores in this population. One of which is the estimated administration time for every test. By and large, these children are more contemplative than their normotypical peers and are not particularly quick to complete timed and randomised paper and pencil tasks. They tend to achieve higher scores in non-timed sub-tests involving abstract reasoning than in timed reasoning sub-tests. Moreover, examiners have reported numerous additional correct answers in some sub-tests if the test continues to be administered until its conclusion, despite the child reaching the interruption criterion of three consecutive failures. That is why the removal of suspension criteria may accelerate test administration. However, it penalises gifted children and may underestimate their abilities (Silverman & Gilman, 2020). There is no indication that any of the examined studies took these recommendations into account, which may affect the quality of the measurement.

It has been shown that differences in measurement quality have a moderating effect on the correlation between brain volume and intelligence and functional connectivity and intelligence under rest conditions. In a bid to ascertain this quality, Gignac & Bates (2017) have presented an essential guide which lists the number of tests, their cognitive dimensions, testing time and correlation with *g* on a 4-point quality scale: 1: "poor"; 2: "fair"; 3: "good"; and 4: "excellent". In accordance with these criteria, 42% of the 23 articles that were reviewed would be categorised as "good" (Bathelt et al., 2019; Clayden et al., 2012; Kim et al., 2016; Kocevar et al., 2019; Langeslag et al., 2013; Navas-Sánchez et al., 2014; Nusbaum et al., 2017; Solé-Casals et al., 2019; Tamnes et al., 2011; Suprano et al., 2019) while the remaining 58% would classify as "fair".

4.4. Cut-off point between giftedness and normotypical IQ

While 79% of the selected studies correlate neurobiological measures with IQ, they do not produce a statistical comparison between gifted and non-gifted groups. It may be a misinterpretation to consider that both study types should inevitably converge towards the same results, as it may be that the group with a high IQ is not simply found at one end of the continuum of general intelligence and corresponding brain properties, but may present qualitatively different structural and functional characteristics (Navas-Sánchez et al., 2014). Moreover, only three of the five studies that make inter-group comparisons (Nusbaum et al.,2017; Solé-Casals et al., 2019; Suprano et al., 2019) follow the recommendations of the APA (American Psychological Association) (American Educational Research Association, American Psychological Association, National Council on Measurement and Education, 2014) predicated on a cut-off point of 2 standard deviations above the mean (IQ of 130 in Wechsler) to identify gifted and non-gifted children. The cut-off points established in the remaining two studies (Khundrakpam et al., 2017; Navas-Sánchez, 2014) are close to the population mean, despite research indicating that as the intellectual profile distances itself from the normotypical scores, the differential characteristics of cognitive functioning are quantitatively and qualitatively greater (Sastre-Riba & Ortiz, 2018).

4.5. Regions of brain under study and IQ-related neurobiological findings

The findings of the morphometric research under review show that brain volume, volumes of grey and white matter, the volume of some sub-cortical structures, such as the striatum, and the thickness and surface area of some cortical regions have positive correlations with IQ. However, 72% of the research papers predominantly focus on the anatomical characteristics of the cerebral cortex, related to logico-deductive reasoning, whereas only 28% examine sub-cortical structures related to creativity and motivation, despite the extensive evidence that they are linked to higher order cognition (Gómez-León, 2020a; 2020b).

White matter plays a key role during the development of cognitive functions. Indeed, as distant regions of the brain become more efficiently interconnected, so the capacity to transfer and analyse information also increases in efficiency, thereby contributing significantly to processing speed and cognitive development. In respect of the research papers that have assessed the integrity of white matter in the brain, 87% have examined both cortical and sub-cortical regions and detected positive correlation with IQ. While this greater number of inter- and intra-hemispherical connections has also been frequently associated with creative thinking (Gómez-León, 2020b), none of the reviewed research papers has assessed whether or not, or the extent to which, these results are due to the overlapping effects of complex profiles where convergent and divergent processes interact.

Studies that refer to the relationship between the functional connectivity of neuronal connections and cognitive ability show positive correlation between the local and global efficiency of the network and the logico-deductive skills measured by IQ. It is thought that cognitive ability depends on the contributions of different regions of the brain which work together as an integrated network and interact to produce variations in the system at every stage of development. When gifted groups are compared to different profiles on the Wechsler scale, from a heterogeneous (score >130 in verbal comprehension or perceptual reasoning) and homogeneous perspective (score >130 on both scales), greater structural and functional connectivity is detected in the homogeneous group (Nusbaum et al., 2017; Suprano et al., 2019). Furthermore, recent neurocognitive research has shown that the integration of the neural network, its dynamic interaction, and the capacity to reach complex network statuses which facilitate adaptive problem-solving is greater in processes related to creativity than in those related to intelligence (Kenett et al., 2018). However, the study produced by Navas-Sánchez et al. (2014) is the only one to have used open-response tasks which enable the relationship between network integration and interaction, on the one hand, and creativity, on the other, to be studied in complex gifted profiles.

4.6. Generalisation of results produced by neuroimaging techniques among gifted profiles

The reduction of the intelligence construct to a single dimension may complicate the task of identifying a suitable instrument with which to measure it. Binet, as author of the first IQ tests, was aware of the limitations of their scale and had to disregard creativity tasks because he was unable to identify a rigorous method by which to assess them, which conditioned the instrument that he subsequently used to measure intelligence (Sternberg & O'Hara, 2005).

Wechsler, the author of the tests used by 96% of reviewed studies, admits that intelligence, as he perceives it, cannot be measured by any test, or at least, not entirely and, in any event, not directly, "our intelligence tests measure effectively only a portion of and not all of the capacities entering into intelligent behaviour" (Wechsler, 1943, p. 101). This author suggests that intelligence tests, as a measure of intellectual ability, only explain between 50% and 70% of intelligent behaviour, while the rest is dependent upon non-intellective factors. Moreover, if there is a contradiction between psychometric and qualitative data, he advises that the latter should prevail over the former (Wechsler, 1943).

While most differential pedagogy authors agree that basing the concept of intelligence exclusively on the scores of IQ tests overlooks many important aspects of mental capacity (Pfeiffer, 2020), all the studies under review have associated intelligence with logico-deductive reasoning and academic ability measured by IQ. This kind of test is related to memorisation and reproductive learning processes. However, it does not assess the capacity to adapt to unfamiliar situations or solve new and complex problems, which requires skills related to creativity and divergent thinking (Sternberg & O'Hara, 2005).

High levels of creativity are associated with a higher-than-average IQ score. Furthermore, the greater the demand for creative potential, the higher the necessary minimum IQ thresholds (Jiménez et al.,2008). Scientific evidence has repeatedly shown that gifted children and adolescents not only have a higher IQ and better executive functioning, but also an extraordinary level of creativity and a higher level of motivation for the task at hand (Gómez-León, 2020a; 2020b; Jiménez et al., 2008; Pfeiffer, 2020; Renzulli, 2021; Sastre-Riba & Ortiz, 2018). That is why 92% of the authors of the most commonly used in giftedness assessments, including Renzulli, Pfeiffer, Reynolds (RIAS), Kaufman, Elliot (BAS3), Raven, and the Wechsler authors, agree that the use of a single dimension to identify giftedness provides a limited sample of the ability profile of a child or adolescent, which means that their ability or potential may be over or under-estimated. Notwithstanding the foregoing, the only research paper to consider this aspect is the study produced by Navas-Sánchez et al. (2014). By way of tasks that can be classified as cognitive, motivational and creative, these authors have discovered that gifted children (high IQ and high level of creativity), as opposed to children who only exhibit a high IQ, not only used more efficient and innovative strategies to solve new and complex problems, but were also characterised by a different brain structure:

- Greater intra-hemispheric connectivity in some regions of the corpus callosum related to fluid reasoning, executive functioning and working memory.
- Greater connectivity in frontoparietal networks and frontostriatal circuits involved in creative thinking, analogy processing and motivation.
- Greater surface area on the bilateral visual cortex related to the processing of enriched mental imagery related to visuospatial working memory.

According to these authors, a high IQ could improve information processing capacity between hemispheres, but giftedness, i.e., a high IQ along with a high level of creativity and motivation, may pave the way for greater participation in increasingly difficult and unfamiliar situations, which would equate to an adaptive advantage, since it would increase the pace of learning, cognitive flexibility and the adaptation of the whole system to constant changes in the environment and the system itself.

5. Conclusion

Individual differences affect the ability to learn, adapt to changes in the environment and solve new and complex problems. The latest neuroimaging studies have represented an unprecedented advance in the development of instruments that enable the neural correlates of these differences to be examined. However, these advances are in contrast with the instrument used to measure intelligence. An instrument based on the traditional and reductionist concept developed in the early 20th century, in which intelligence is deemed to be synonymous with IQ.

Differential pedagogy specialists take the view that giftedness represents a multidimensional neurobiological configuration that may or may not be linked to the scores obtained in IQ tests. This discipline considers giftedness to be underpinned by logico-deductive and creative components that must be measured for the purpose of identifying giftedness. However, neuroimaging studies that examine how these components interact in the development of gifted children are few and far between. One of the main reasons may be that the relevant systems and processes have been researched separately and independently of each other.

Only one of the reviewed studies has taken into consideration the intellectual profile of participants, based on convergent and divergent tasks, and reaches the conclusion that a high IQ and giftedness (high IQ and high level of creativity) are two different constructs. Gifted children have more efficient brains with densely interconnected regions which facilitate mutual interaction between various cognitive processes. This, in turn, paves the way for the children to propose more effective solutions adapted to the specific domain in which they are active.

These results suggest that most of the data currently extracted from neuroimaging studies cannot be generalised within the gifted population. It is evident that a genuine inter-disciplinary study is needed to establish a consensus as to the validity and reliability of the construct that is to be measured, and of the instruments used to this end.

In order to adopt suitable educational programmes, it is essential to ascertain, both from a biological and a cognitive perspective, the various skills and processes by which giftedness is able to develop. If the development of skills in the 21st century "consists of applying relevant knowledge, research skills, creative and critical thinking skills, and interpersonal skills to the solution of real problems" (Renzulli, 2021, p. 25), it is suggested that the study of neural correlates of intelligence should focus on these skills.

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