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Is intelligence equivalent to executive functions?

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Abstract

Background: Since the mid 19th century, cognitive and behavioral neurosciences have attempted to find the neurological bases of intellectual abilities. During the early 20th century the psychometric concept of "intelligence" was coined; and toward the end of the 20th century the neuropsychological concept of "executive functions" was introduced. Controversies, however, remain about the unity or heterogeneity of so-called executive functions. **Method:** It is proposed that two major executive functions could be separated: metacognitive –or intellectual– and emotional/motivational. A similar distinction has been suggested by several authors. Standard definitions of intelligence implicitly assume that executive functions represent the fundamental components of intelligence. **Results:** Research has demonstrated that, if considered as a whole, executive functions only partially correspond to the psychometric concept of intelligence; whereas some specific executive functions clearly correspond to intelligence, some others do not involve intelligence. **Conclusions:** If using a major distinction between metacognitive –or simply "intellectual"—executive functions, and emotional/ motivational – or simply non-intellectual—executive functions, it becomes evident that general intelligence can be equated with metacognitive executive functions but not with emotional/ motivational executive functions.

Keywords: Intelligence, executive functions, metacognition, neuropsychology, neuroimaging.

Resumen

¿Es inteligencia equivalente a funciones ejecutivas? **Antecedentes:** desde mediados del siglo XIX las neurociencias cognitivas y comportamentales han intentado hallar las bases neurológicas de las habilidades intelectuales. A comienzos del siglo XX se acuña el concepto psicométrico de "inteligencia"; y hacia finales del siglo XX se introduce el concepto neuropsicológico de "funciones ejecutivas". Sin embargo, continúan existiendo controversias acerca de la unidad o heterogeneidad de las llamadas funciones ejecutivas. **Método:** se propone que es posible distinguir dos funciones ejecutivas básicas: metacognitivas –o intelectuales– y emocionales/motivacionales. Diversos autores han propuesto una distinción similar. Las definiciones estándar de inteligencia implícitamente asumen que las funciones ejecutivas representan los componentes fundamentales de la inteligencia. **Resultados:** la investigación ha demostrado que, consideradas en conjunto, las funciones ejecutivas corresponden solo en forma parcial al concepto psicométrico de inteligencia; en tanto que algunas funciones ejecutivas claramente corresponden a inteligencia, otras no se asocian con la inteligencia. **Conclusiones:** utilizando la distinción entre funciones ejecutivas metacognitivas "o simplemente "intelectuales" –y funciones ejecutivas emocionales/motivacionales "o simplemente "no intelectuales"–, se hace evidente que la inteligencia general se puede equiparar con las funciones ejecutivas metacognitivas, pero no con las funciones ejecutivas emocionales/motivacionales.

Palabras clave: inteligencia, funciones ejecutivas, metacognición, neuropsicología, neuroimágenes.

Since Broca's initial observation (1863) about the disturbances in spoken language associated with brain pathologies, cognitive and behavioral neurosciences have striven to find the neurological bases of intellectual abilities. This research approach was based on the observation of patients with brain pathologies, most frequently, cerebrovascular accidents, tumors, and traumatic brain injuries. The usual procedure was to correlate the intellectual disturbance with the lesion site, assuming that under normal circumstances, the impaired area was the neurological support of that specific intellectual ability.

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During recent years, an increased interest in understanding so-called "executive functions" and their involvement in diverse intellectual abilities such as reasoning, thinking, and problem-solving has also been observed (Diamond, 2013; Friedman & Miyake, 2017). However, many questions remain unsolved, such as the relation between executive functions and intelligence (e.g., García-Molina et al., 2010).

What Defines "Executive Functions"?

The concept of "executive function" has become a fundamental milestone in contemporary cognitive neurosciences (Jurado & Rosselli, 2007). The observation that the frontal lobes are involved in intellectual behaviors, including planning, self-monitoring, problem solving, reasoning, and working memory, resulted in the comprehensive term "executive function", "executive functions", or simply "executive functioning". Luria (1980) first suggested the

idea that the frontal lobe has an executive role. He distinguished three functional units in the brain: (a) arousal-motivation (limbic and reticular systems); (b) receiving, processing, and storing information (postrolandic cortical areas); and (c) programming, controlling, and verifying activity (frontal lobes). Luria mentions that this third unit has an executive function. Later, Lezak (1983) introduced the term as the dimension of human behavior that deals with "how" behavior is expressed. More recently, Baddeley coined the term "dysexecutive syndrome" to refer to the impairments in executive functions frequently found as a consequence of frontal lobe pathologies.

Heterogeneity of Executive Functions

Up to date there is some disagreement around the question of unity or heterogeneity of executive functions (Frias, Dixon, & Strauss, 2006). It means, should we refer to one fundamental executive function? Or to a diversity of executive functions? Indeed, it has not been easy to find a single unitary factor saturating the different executive function tasks and diverse interpretations have been suggested.

Some authors have considered that behavior inhibition represents the potentially single factor responsible for successful performance in diverse executive tests (Barkley, 1997) alone or in combination with working memory (Pennington & Ozonoff, 1996). Salthouse (1996, 2005) has suggested that reasoning and perceptual speed could be regarded as the underlying factors saturating all the executive functions. He points out that performance on two basic tests of executive functioning, the Wisconsin Card Sorting Test and the Controlled Oral Word Association Test were strongly correlated with reasoning ability and perceptual speed.

Other authors do not support the existence of such a unitary factor, suggesting that indeed executive functions include a diversity of subcomponents and it is not correct to assume a single underlying factor. Godefroy et al. (1999) emphasized that certain frontal lobe patients perform well on some tests purported to assess executive abilities but not on others. Furthermore, factor analysis have also supported that executive functions include several subcomponents (Stout & Chaminade , 2007; Mäntylä, Carelli, & Forman, 2007). For example, Testa et al. (2012) performed a factor analysis of 19 executive function tests administered to a nonclinical sample of 200 adults, and found 6 independent factors: prospective working memory, set-shifting and interference management, task analysis, response inhibition, strategy generation and regulation, and self-monitoring and set-maintenance. It is important to emphasize that correlations among different executive tests are frequently moderate or low, and many times lacking statistical significance (Friedman et al., 2006; Lehto, 1996; Salthouse et al., 2003), suggesting that they measure different underlying factors.

Meanwhile, other authors have taken an intermediate point of view. Miyake et al. (2000) for example studied three executive function abilities (shifting, updating, and inhibition) and concluded that, although they are clearly distinguishable, they do share some underlying commonality.

Some recent papers have attempted to relate intelligence and executive functions. Friedman & Miyake (2017) emphasized that executive functions show a general pattern of shared but distinct functions, a pattern described as "unity and diversity". They reviewed evidence that across multiple ages and populations, commonly studied executive functions: (a) are robustly correlated but separable when measured with latent variables; (b) are not the same as general intelligence or *g*; (c) are highly heritable at the latent level and seemingly also are highly polygenic; and (d) activate both common and specific neural areas and can be linked to individual differences in neural activation, volume, and connectivity. Jewsbury, Bowden, & Duff (2017) observed that in the Cattell-Horn-Carroll (CHC) model of cognitive abilities executive function tests are found to be well represented, suggesting a clear association between executive functions and intellectual abilities. Roebers (2017) emphasizes that executive function and metacognition are higher-order cognitive processes that undergo continuous improvements during childhood.

Two Basic Executive Functions

Patients with prefrontal pathology can present intellectual disturbances, such as problem solving difficulties, abstraction defects, and reasoning impairments; and they also may present emotional/ behavioral changes without intellectual disturbances, as clearly illustrated in Phineas Gage classical case (Harlow, 1848). Consequently, it may be conjectured that there are at least two different, but related types of executive functions, and two different dysexecutive syndromes. Furthermore, these two fundamental executive functions probably appeared at different historical moments (Ardila, 2008) and develop in children at different age (Ardila, 2013).

This idea that there are two basic executive functions has been suggested by different authors (e.g., Fuster, 2001; Happaney et al., 2004; Stuss, 2004, 2011). For instance, a distinction between the "cool" cognitive aspects of executive functions has been proposed, which are more associated with dorsolateral regions of the prefrontal cortex, and the "hot" affective aspects, which are more associated with the ventral and medial regions (Zelazo & Muller, 2002). This hot/cool distinction has been applied to the development of executive functions in children (Hongwanishku et al., 2005); it was observed that, whereas cool (metacognitive) executive functions significantly correlated with general intellectual ability ("intelligence"), hot (emotional/ motivational) executive functions are not related to general intellectual functioning (verbal mental age and performance mental age). It could be argued, however, that the use of the terms "cool" and "hot" could generate confusion, because behavioral symptoms could indeed be regarded as "cool" or "hot". But these terms are just proposed names to refer to these two fundamental executive functions. As a matter of fact, this basic distinction could be named in diverse ways, for instance, dorsolateral and mesial/orbital executive functions; behavioral and cognitive executive functions; emotion-related and reasoning-related executive functions; intellectual and non-intellectual executive functions, etc.

I am proposing that these two fundamental executive functions, could be named and characterized in the following way:

(a) ''Metacognitive –or intellectual– executive functions" which includes temporality of behavior, problem solving, abstracting, planning, anticipating the consequences of behavior, strategy development and implementation, and working memory (the usual understanding of executive functions, generally measured in neuropsychology executive functions tests). These are abilities mostly related to the dorsolateral area of the prefrontal cortex (Stuss & Knight, 2002). As a matter of fact, the dorsolateral

prefrontal cortex has been observed to participate in planning, abstracting, problem solving, controlling cognition (metacognition) and working memory tasks. Using fMRI dorsolateral prefrontal activation has been found in tasks such as solving the Tower of Hanoi (Fincham et al., 2002), Controlled Word Association Test (letter fluency) (Baldo et al., 2006), working memory (Yoon et al., 2007), and solving the Wisconsin Card Sorting Test (Lie et al., 2006).

(b) ''Emotional/motivational executive functions", which are responsible for coordinating cognition and emotion. In other words, they have the ability to fulfill basic impulses following socially acceptable strategies. Phineas Gage can be considered as the most typical example of a disturbance in emotional/ motivational executive functions. For these executive functions, what is most important does not necessarily include what the best conceptual and intellectual result is, but what is in accordance with personal impulses (Bechara & Martin, 2004). In that regard, the core function of the prefrontal lobe is to get an acceptable justification for limbic impulses. Following socially acceptable strategies actually involves inhibition of selfish or unsociable basic impulses in the first place, but not necessarily arriving at the best conceptual solution. It has been found that emotional contents fail to interact with cognition in executive functions –working memory—tests (Roman et al., 2015) supporting that they correspond to different executive functions dimensions, depending upon different prefrontal areas: dorsolateral and mediobasal.

It is important to note that these two fundamental executive functions have not only a different evolutionary history (Ardila, 2009) but also appear in the child development at different moments: emotional executive functions (such as attention control) develop earlier in life (during the first year), before the development of metacognitive executive functions (such as planning and verbal fluency), which develop around the age of 3 and are correlated with the development of a grammatical language (Ardila, 2013).

What is Intelligence?

Different definitions of intelligence have been proposed (e.g., Binet, 1908; Jensen, 1980; Sternberg, 1985; Wechsler, 1944). Wechsler's definition represents a comprehensive and frequently used definition of intelligence. Wechsler (1944) defined intelligence as "the aggregate or global capacity of the individual to act purposefully, to think rationally and to deal effectively with his environment" (p. 3). This definition includes four different elements: (1) Intelligence is an aggregate or global capacity, (2) to act purposefully, (3) to think rationally, and (4) to deal effectively with the environment.

The first element of Wechsler's definition of intelligence refers to a core issue: Is there such a thing as a global or general intelligence, or rather, is intelligence an aggregate of abilities? In his definition, Wechsler does not take a definite position. However, when developing the intelligence scales, he assumes that there is a general intelligence (Full Scale IQ). Yet he also recognizes at least two major subtypes of intelligence: verbal and performance intelligence. So, he implicitly is suggesting that intelligence is both, an aggregate and also a global capacity. This question about one or several intelligences has remained as a polemic question in psychology (see Neisser et al., 1996).

The second element in Wechsler's definition of intelligence ("to act purposefully") could be understood as the control, organization, and planning of behavior. Acting purposefully is evidently a fundamental metacognitive executive function (e.g., Stuss, 2011; Stuss & Knight, 2002).

The third element ("to think rationally") might be understood as either organization of cognition (metacognition) or problem-solving ability. In either case, the definition refers to executive functions.

The final element ("to deal effectively with the environment") refers to the functional criteria of intelligence. Of course, intelligence may be understood not only from a psychometric perspective but also from a functional perspective (Pirozzolo, 1985). Wechsler appropriately recognizes that intelligence has to be considered with regard to the specific environment. Unfortunately, it is not so easy to evaluate the effectiveness in dealing with the environment from the outside. This can only be appropriately evaluated from inside the culture or subculture itself. In this regard, intelligence includes a cultural dimension. Either way, intelligence represents an executive function ability.

In brief, standard definitions of intelligence implicitly assume that executive functions represent the fundamental component of intelligence.

Metacognitive Executive Functions and Intelligence

Since a long time ago, it has been observed that frontal damage is not necessarily associated with evident deficits in psychometric intelligence tests (Hebb, 1939; Hebb & Penfield, 1940). This is true even in cases of bilateral frontal lobectomy. It was somehow surprising to find that intelligence quotient (IQ) in patients with frontal lobe damage could be normal (Hebb, 1945). These initial observations carried out during the 1940s were further supported in neuropsychology (e.g., Brazzelli, Colombo, Della Sala, & Spinnler, 1994; Damasio & Anderson, 1993). Milner (1983), for instance, reported a mean loss of only 7.2 IQ points following dorsolateral frontal lobectomies, with mean postoperative IQ scores remaining in the average range.

Some studies have specifically analyzed the association between executive function measures and psychometric intelligence test scores. Welsh, Pennington, and Groisser (1991) observed that most of the executive function tasks, such as Visual Search (Teuber, Battersby, & Bender, 1955); Verbal Fluency (McCarthy, 1972); Motor Planning (Golden, 1981); Tower of Honoi (Simon, 1975); Wisconsin Card Sorting Test (WCST; Heaton, 1981); and Matching Familial Figures Test (Kagan, 1964) in children were uncorrelated with IQ. Visual Search, Verbal Fluency, WCST, and Tower of Hanoi did not significantly correlate with any IQ measure (Verbal, Quantitative, and Nonverbal) from the Iowa Test of Basic Abilities. In another research, using a 300-subject college-student sample, Ardila, Galeano, and Rosselli (1998) observed that Verbal Fluency tests presented a low but significant correlation (0.20-0.25) with some WAIS verbal subtests, particularly Digits, Arithmetic, and Information. However, WCST scores did not correlate at all with the Verbal, Performance, or Full Scale IQ. Consequently, independence of executive functions from psychometric intelligence may be conjectured. Ardila, Pineda and Rosselli (2000) selected some executive function measures (Wisconsin Card Sorting Test –WCST–), verbal fluency, and Trial Making Test (TMT, Form A and Form B) and calculated the correlation with the Wechsler Intelligence Scale for Children-Revised (WISC-R) scores. Fifty 13- to 16-year-old normal children

were selected. It was found that verbal fluency tests correlated about 0.30 with Verbal Intelligence Quotient (IQ) and Full Scale IQ. In the WCST only Perseverative Errors negatively correlated with Verbal IQ and Full Scale IQ. Two correlations were found to be significant with regard to the TMT: TMT Form B Errors negatively correlated with WISC-R Vocabulary subtest; and TMT Form A Time negatively correlated with Performance IQ. These results support the assumption that traditional intelligence tests are not appropriately evaluating executive functions.

During the 21st century, this relationship between executive functions and general intelligence has remained as a polemic topic (García-Molina et al., 2010; Tirapu Ustárroz, García-Molina, Ríos Lago, & Ardila, 2012; Verdejo-García & Bechara, 2010). García-Molina et al. (2010) reviewed the relationship between intelligence, on the one hand, and working memory and the executive functions construct, on the other; they also reviewed the relationship between intelligence and the prefrontal cortex, as its possible neuroanatomical substrate. The studies that were surveyed present different answers to the question of whether intelligence and the executive functions are one and the same thing. The authors concluded that intelligence and the executive functions are overlapping in some aspects but not in others. Barbey and colleagues (2012) evaluated impairments on the Wechsler Adult Intelligence Scale and Delis-Kaplan Executive Function System in 182 patients with focal brain damage in relation to voxel-based lesion-symptom mapping. Abnormal performance in these tests was observed following damage to a distributed network of left lateralized brain areas (frontal and parietal cortex and white matter association tracts). It has also been pointed out that some executive function tests such as the Wisconsin Card Sorting Test and Verbal Fluency are closely linked to fluid intelligence; and executive dysfunction observed in some clinical conditions such as Parkinson disease can be interpreted to reflect a decrease in fluid intelligence (Roca et al 2012).

Noteworthy, some authors (e.g., Ducan et al., 2000) have suggested that general intelligence is clearly related with the lateral prefrontal cortex, exactly the most important brain area involved in reasoning, problem solving, and in general, meta-cognitive (or intellectual) executive functions (Ardila, Bernal, & Rosselli, 2017; Diamond, 2013; Yuan & Raz, 2014).

Friedman et al. (2006) argued that evidence suggests that executive functions are related to intelligence, despite that this relation was not evident some time ago. The authors examined the relations of fluid and crystallized intelligence and Wechsler Adult Intelligence Scale IQ to three separable executive functions—inhibiting prepotent responses (inhibiting), shifting mental sets (shifting), and updating working memory (updating)—in young adults. Updating was highly correlated with the intelligence measures, but inhibiting and shifting were not. Noteworthy, updating can be considered as a metacognitive executive function, whereas inhibiting and shifting rather correspond to emotional/motivational executive functions. These results suggest that intelligence differentially relate to these three executive functions measurements, indicating that current intelligence tests do not equally assess different executive abilities. This study also suggests that some executive functions are clearly related to intelligence (e.g., updating), whereas others have no significant association with intelligence measures (e.g., inhibiting). Simply speaking, *general intelligence is related to metacognitive executive functions but not to emotional/motivational executive functions*.

Discusion

Whereas "intelligence" is a concept developed in the psychology and particularly psychometric tradition, "executive function" is a concept coined in the cognitive neuroscience domain. It is not surprising that both have remained as parallels concepts in the explanations of human cognition. Research has demonstrated that, if considered as a whole, executive functions only partially corresponds to the psychometric concept of intelligence. Thus, it is evident that some elements of executive functions, or rather, some specific executive functions do clearly correspond to intelligence, whereas some other do not refer to intelligence. If using a major distinction between metacognitive –or simply "intellectual"—executive functions, and emotional/ motivational – or simply non-intellectual—executive functions, it becomes evident that general intelligence can be equate with metacognitive executive functions but not with emotional/ motivational executive functions. Recently it has been proposed that cognitive tests tap domain-general executive processes; executive processes are tapped in an overlapping manner across cognitive tests such that they are required more often than domain-specific ones (Kovacs & Conway, 2016).

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