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Article

Executive Function and Metacognition: Relations and Measure on High Intellectual Ability in Typical Schoolchildren

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Abstract: The current understanding of high intellectual ability (HIA) involves considering the multidimensional nature of the skills that comprise it. In addition, conceptual advances related to how individuals manage the high intellectual resources available to them may help explain the possible gap between performance and high levels of competence. Understanding the role of executive functioning and metacognition in relation to the management of these resources is essential. Nonetheless, to date, the trajectory of their study is diverse, and empirical and measured evidence in this regard is limited. Thus, the objective of this work was to understand the relationship between executive functions and metacognition (and its components), as well as the measurement of these factors and their reliability. The study sample comprised schoolchildren (n = 43) with an HIA and a control group (n = 46) of schoolchildren with typical intelligence levels. Network analysis revealed differential intergroup connections between the executive functioning components as well as between those of metacognition and for each construct. The greatest relational weight was for metacognition components, with the most robust relationship being found in the group with HIA with metacognitive regulation, flexibility, and verbal working memory versus metacognitive awareness and inhibition in the typical group. Measurement derivations and their application in educational interventions to optimise the expression of high potential are also discussed.

Keywords: HIA expression; modulator factor; executive function; metacognition; components; measure

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1. Introduction

Higher cognitive functions, among which executive functioning and metacognition stand out, play a fundamental role in the development and intellectual activity (both from early childhood and throughout life) as regulators of available resources. In the differential field of development and intellectual functioning, research in high intellectual ability (HIA) highlights the importance of the management of intellectual resources as one of the most relevant endogenous modulators that conditions the expression of high intellectual potential [1]. The distribution of these resources may help to explain the difference between competence and performance observed in some people to whom such resources are available, but whose achievements do not reach the expected levels of excellence. Within this framework, HIA is understood not as a static quality fixed in the mind, but as the result of various interacting factors that influence the development of elevated levels of neurobiological potential in complex functions of the brain [2] that allow its more effective and efficient use. In other words, both metacognition and the management of high potential through executive functioning 'hot and cold' are essential to self-regulate and monitor intellectual resources, build knowledge structures, perceive the environment, and make appropriate decisions.

Therefore, the regulation of intellectual resources has a decisive role both in typical and differential cognitive functioning, as well as in its results: learning and academic performance or creativity. This involves understanding the role of executive functions and metacognition, two constructs related to this regulation of resources but whose roles remain unclarified in the scientific literature. The definition and measurement of executive functions are still imprecise [3], but researchers [4–6] have shown that they comprise three core-components: (1) inhibition of overbearing responses or irrelevant information; (2) flexibility in searching for new alternatives, categories, or information to improve a response; and (3) working memory as the ability to actively keep an objective, rule, or information in mind [7,8]. One of the most relevant gains in cognitive development is the ability to intentionally regulate behavior and thinking, meaning that executive functions play important roles in solving tasks in everyday life [9,10] and even as predictors of motivation [11] and school performance. Despite this relevance and the relationship of executive functions with neurological bases linked to intellectual functioning [12,13], their measurement is still 'impure' [14].

Metacognition is related to a higher self-reflective cognitive process that can be used in the regulation of resolution [15]. Although metacognition does not yet have a precise definition in the scientific literature, it involves the use of both declarative skills (awareness or knowledge of resources) and procedural skills (regulation of resources) as processes during learning and problem-solving tasks. Metacognition is initially implicit but gradually becomes accessible to the conscience to the point where individuals can eventually intentionally use it. In general, metacognition influences academic performance, both in terms of the declarative components of metacognitive awareness [16,17] as well as the procedural component of metacognitive regulation. This influence progressively increases during childhood to become increasingly relevant [18,19].

Some authors also highlight the importance of the role that the progressive self-perception of competence has in terms of motivation and long-term effort [20,21] as one of the most relevant modulating factors for the optimal expression of HIA [22,23]. Therefore, two types of regulation can be distinguished: cognitive, which would be related to the perception of one's own general competence, and metacognitive regulation, understood as regulatory self-monitoring in relation to resolution and learning [24]. Metacognitive abilities are usually measured through questionnaires or by asking participants questions while they work to complete a task [25], either globally [26] or by specifying between conscious and metacognitive regulation [27]. However, research in this area is still conceptually confused [28] and so the measurement of metacognitive abilities is not yet precise or reliable.

Given their relevance of metacognition, it is important to understand the relationship or integration between the executive function and metacognition constructs involved in intellectual regulation and resolution, as well how the reliability of their measurement can be optimised. The question has been discussed in a context of the so-called 'jingle-jangle' issue [29,30] for which the conceptual operationalisation is still confusing and the measurements are imprecise. Indeed, the same names are used to refer to different components or have been applied with little care for their validity. In addition to the need for conceptual and measurement clarification regarding these constructs, truly little scientific work has focused on how executive function and metacognition constructs can facilitate progress in this field [10,31]. Moreover, the studies performed to date have not addressed how these metrics could be improved [32] and also included conceptual and methodological disparities, thereby biasing their interpretation in this regard.

Regardless, executive functioning and metacognition are intricately linked. They are both high-level processes related to the regulation of intellectual resources and behaviour which share theoretical explanations (for example, for the control of intellectual functioning, learning, or creativity). They also follow similar emergency and developmental trajectories and are both associated with the maturation of similar brain areas [33]. Therefore, it is important to seek conceptual clarification of these constructs, improve the reliability and validity of their measurement, and understand their presumed relationship in the regulation of intellectual resources and their role in modulating the neural efficiency of

HIA functioning. The latter could explain the failure sometimes observed between initial childhood promise and crystallisation of the expression of high potential in adulthood.

Therefore, the integration between executive functions and metacognition supports the perception and regulation of resources available to children. This allows them to become aware of and to integrate their strengths and limitations, assess their own competencies, and to make the necessary adjustments to achieve an adequate performance. That is, this integration facilitates their ability to become agents of their own learning, creating a better fit between competencies and performance, maintaining objectives, and transferring knowledge of their achievements to new learning and creative situations. In short, these two constructs can facilitate excellent intellectual performance and the optimal expression of high intellectual potential [34].

For this reason, the currently heterogeneous definitions of multidimensional psychological constructs, as well as their poor measurement reliabilities, is a fundamental problem for researchers. Furthermore, the components of executive functioning cannot be measured in isolation from the cognitive processes in which they are immersed, thereby contributing to the impurity of the task [35]. Moreover, in addition to their multidimensionality, the components of executive functioning and metacognition are also interrelated, which therefore calls for more sophisticated evaluation models, such as network analysis [36]. The latter considers the complexity and diversity of these constructs from a dynamic and multi-causal perspective. This allows their interrelationships in terms of resolve to be captured, thereby directly estimating the relationship between all of the variables considered.

Accordingly, the objective of this work was to compare schoolchildren with HIA or with typical intelligence in order to understand the relationship between executive functions (and their core components) and metacognition (and its components), as well as the efficacy of these measures and their relationships.

2. Materials and Methods

2.1. Sample

The sample was drawn by intentional non-probabilistic sampling. A total of n = 89 schoolchildren aged between 11 and 12 years (*Mage* = 11.48, *SDage* = 0.50) participated, n = 51 were male and n = 38 were female. The n = 43 were children with HIA participating in the extracurricular enrichment program of the University of La Rioja who were previously diagnosed as having HIA by the educational psychologist of their school and according to the Castelló model [37]. Participants with a score in the 75th percentile or above in all measured intellectual aptitudes were categorized as gifted [37]. Those whose score was in the 90th percentile or above in any one or various intellectual aptitudes were categorized as having simple or complex talents. They were paired by age with n = 46 children with typical intelligence who attended a public educational centre.

2.2. Instruments

The following instruments were employed:

1. Executive functions. To capture the core-components of inhibition, flexibility, and working memory (visuospatial and verbal), we administered (a) using the free version of the Psychology Experiment Building Language (PEBL) software (version 0.14) [38]: the (1) Berg Task Card Sorting Test (BCST) [39] as a measure of learning and strategy changes or cognitive flexibility; (2) the Go/NoGo task [40] related to the measure of inhibition; and (3) the Corsi Block Task [41] standardised by Kessels et al. [42] to assess visuospatial working memory; and (b) through the Wechsler Intelligence Scale for children (WISC-V) [43], Digits subtest to evaluate verbal working memory.
2. Metacognition. The Metacognitive Awareness Inventory (MAI) questionnaire by Schraw and Denninson [27], in the version adapted to Spanish by Domènech [44] was used to test metacognitive consciousness and regulation [45].

2.3. Procedure

The measurement instruments were administered collectively, in groups of 10 students, during enrichment program hours and in a classroom specially prepared for this purpose, under the supervision of two researchers.

The tasks and questionnaire were administered in the following order:

1. Executive functioning tasks: the BCST (10 min), Go/NoGo task (15 min), and Corsi Block Task (10 min), which together lasted about 50 min including instructions before each task.
2. The adapted MAI questionnaire, which lasted about 10 min, including instructions.
3. Subsequently, the Digits subtest of the WISC-V (2015) was individually administered, which took an average of 10 min, including instructions.

For all participants, parents provided written informed consent in order for their child to participate in the study. Participants were informed of the confidentiality of their responses and of the voluntary nature of the study. No incentive was provided for their participation. The investigation followed the Helsinki agreements.

2.4. Data Analysis

The data analysis consisted of:

1. Calculation of the mean, standard deviation (SD), and deviation of the standard error (SE) descriptive statistics.
2. Network analysis using the Fruchterman–Reingold algorithm [46] by employing Haslbeck's Mixed Graphical Model (MGM) [47] such that if two nodes were connected in the resulting figure, they were considered statistically related after controlling for the effect of all the other variables in the network. To make inferences from the network, we calculated three centrality indices for the nodes: (a) degree-strength, (b) betweenness, (c) closeness, and (d) the expected influence.

We obtained the confidence intervals of the edges to estimate the degree of precision of the network (edges) and to verify its stability; the centrality strength indices of the nodes were calculated using the bootstrap analysis method [48]. The statistical programs SPSS v24 [49], R [50], R bootnet [48], and R graph [51] were used for these analyses.

3. Results

Table 1 shows a comparison of the intergroup results for each of the metacognition and executive functioning tasks administered and in the latter case, for each core-component (flexibility, inhibition, visuospatial working memory, and verbal working memory).

Table 1. Executive functioning and Metacognition. Intergroup comparation.

		M		**SD**		**SE**	
		HIA	**Typical**	**HIA**	**Typical**	**HIA**	**Typical**
BCST	Categories completed	5.209	5.021	1.946	3.044	0.296	0.448
	Perseverative errors	14.361	29.748	5.015	17.075	0.764	2.517
	Set maintenance errors	2.627	1.804	1.234	1.485	0.188	0.218
GO/NO-GO	Total correct	276.767	282.782	27.054	23.438	4.125	3.455
	Total errors	43.255	37.217	26.952	23.438	4.110	3.455
CORSI BLOCK	Block span	5.000	4.902	0.872	0.916	0.133	0.135
DIGIT	Direct digits	9.090	7.410	1.477	2.671	0.225	0.394
	Reverse digits	8.140	6.760	1.754	1.876	0.267	0.277
	Total digits	17.210	14.170	2.596	3.302	0.396	0.487
MAI	Consciousness	4.08206	4.03206	0.553	0.428	0.084	0.0632
	Regulation	3.259	3.442	0.732	0.571	0.111	0.084

Note. HIA = High intellectual ability; BCST = Berg Card Sorting Test; MAI = Metacognitive Awareness Inventory.

As shown, the highest mean intergroup differences were reported in the executive components of verbal working memory, flexibility, and inhibition, with the highest values being obtained by the participants with HIA. These participants also showed higher scores and made fewer mistakes on most tasks, except in the inhibition sub-category, in which the participants with typical intelligence obtained more correct answers and made fewer mistakes. In addition, the estimated executive and metacognitive differential functioning network and its components are represented in Figure 1.

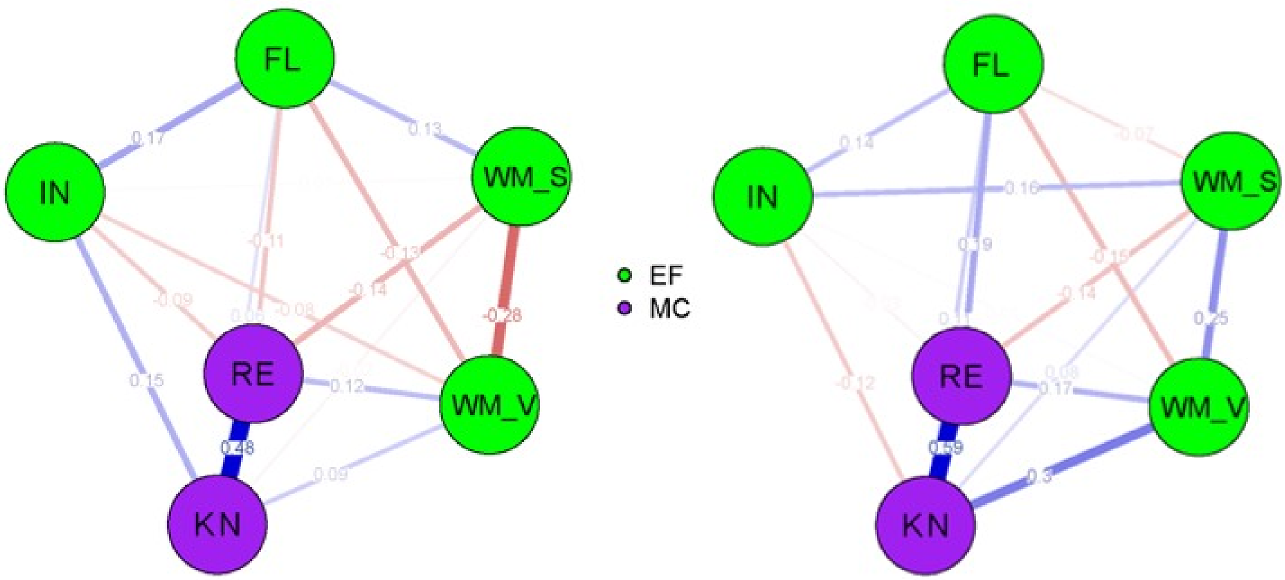


Figure 1. Estimated executive and metacognitive differential functioning network. (**a**) Network from typical sample; (**b**) Network from HIA sample. MC = metacognition; EF = executive functions; RE = regulation; KN = awareness/knowledge; WM_V = verbal working memory; WM_S = visuospatial working memory; FL = flexibility; IN = inhibition. EF = executive functioning (green); MC = metacognition (purple).

The result of this analysis was a compact graph with interconnected variables comprising six nodes (four representing components of executive functioning and two for metacognition), as well as 13 edges. Most of the relationships were more strongly weighted and were more positive in the HIA group. However, there were intra and inter-domain differences between the study groups for these relationships. The most weighted dimension in both groups of participants was metacognition, which was strongly interconnected ($W_{typical}$ = 0.48 and W_{HIA} = 0.59), although the relationship weight (edge weights) was higher between its awareness and regulation components in the group with HIA. Furthermore, intergroup differences were also reported for executive functioning. The strongest connection in the HIA group was between verbal working memory and visuospatial working memory (W_{HIA} = 0.25), while the group of typical participants showed the opposite relationship between these same variables ($W_{typical}$ = −0.28). The strongest connection was between inhibition and flexibility ($W_{typical}$ = 0.17).

The interdomain relationships between the metacognitive components and those of executive functioning also significantly varied between the study groups. In the participants with HIA, flexibility had the most relationships, while there were more relationships for inhibition in the typical group. Specifically, the most robust relationship in the group with HIA was between metacognitive awareness and verbal working memory (W_{HIA} = 0.30), highlighting the idea that flexibility is related to metacognitive regulation (W_{HIA} = 0.19) and verbal working memory (W_{HIA} = 0.17), but not with inhibition, which was only related to the metacognitive awareness component (W_{HIA} = 0.12).

In the group of typical participants, the most robust relationship was between inhibition and metacognitive awareness ($W_{typical}$ = 0.15), as well as with metacognitive regulation

($W_{typical}$ = 0.09), with a negative connection between metacognitive regulation and visuospatial working memory ($W_{typical}$ = −0.14), verbal working memory ($W_{typical}$ = −0.12), and flexibility ($W_{typical}$ = 0.11). Finally, it should be noted that the relational weight with the rest of the intra and inter-domain components was greater for flexibility in the group with HIA, although verbal working memory presented more robust relationships; in contrast, in the typical group, inhibition had the most interrelationships in terms of number and robustness.

Figure 2 represents the centrality indices and expected influence for these data, which were then used to estimate the most relevant node in each study group based on their connection patterns.

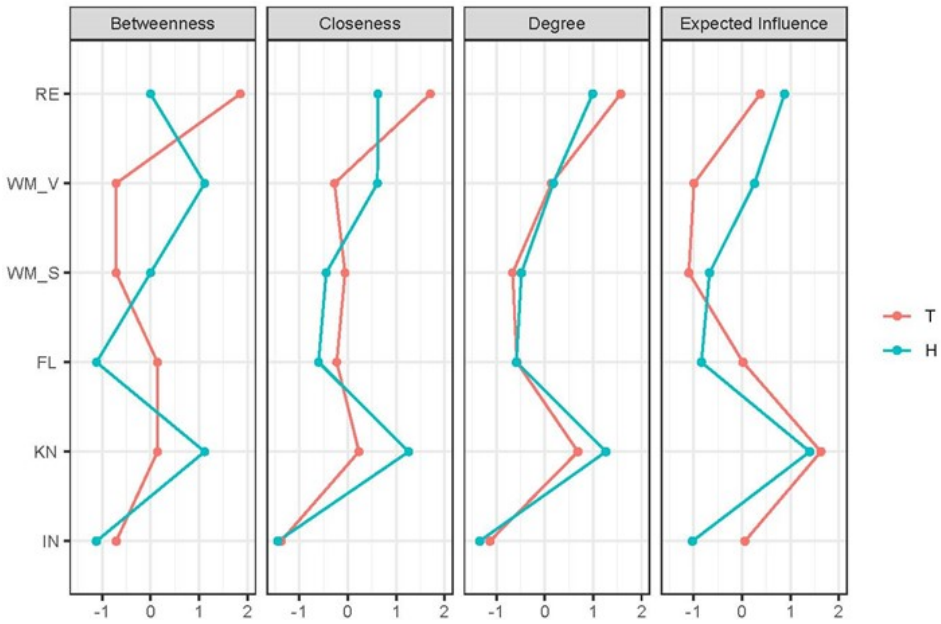


Figure 2. Centrality indices and expected influence for the estimated network of executive functioning and metacognition according to type of development. RE = regulation; KN = awareness/knowledge; WM_V = verbal working memory; WM_S = visuospatial working memory; FL = flexibility; IN = inhibition; T = typical group; H = High intellectual ability group.

As shown, there were statistically significant intergroup differences with respect to the three indices of node centrality. In the group with HIA, the nodes with the highest centrality index strength that influenced other nodes were the awareness metacognitive component (C_S = 1.262) and the verbal working memory executive component (C_S = 1.262) followed by that of metacognitive regulation, with this latter component also being the most influential node in the typical group (C_S = 1.365).

Regarding the betweenness index between executive functioning and metacognition in students with HIA, the nodes that best connected with the rest in the group were metacognitive awareness and verbal working memory (both C_C = 1.118), while in the group of typical participants it was the metacognitive regulation node (C_C = 1.864). In agreement with the above, for the closeness index, the node that best predicted other nodes in the group with HIA was metacognitive awareness (C_B = 1.259), while in the typical group it was metacognitive regulation (C_B = 1.708). The highest nodes for expected influence were consciousness and metacognitive regulation in the group with HIA and metacognitive awareness in the typical group. Notwithstanding, considering the magnitude of the rest of the centrality indices, these results indicated that the core variable in this model was metacognition, albeit with different intergroup components; the metacognitive component of awareness was the highest in the group with HIA versus the metacognitive regulation component in the typical group.

Figure 3 represents the stability of the edges to estimate the network obtained, according to the type of child development.

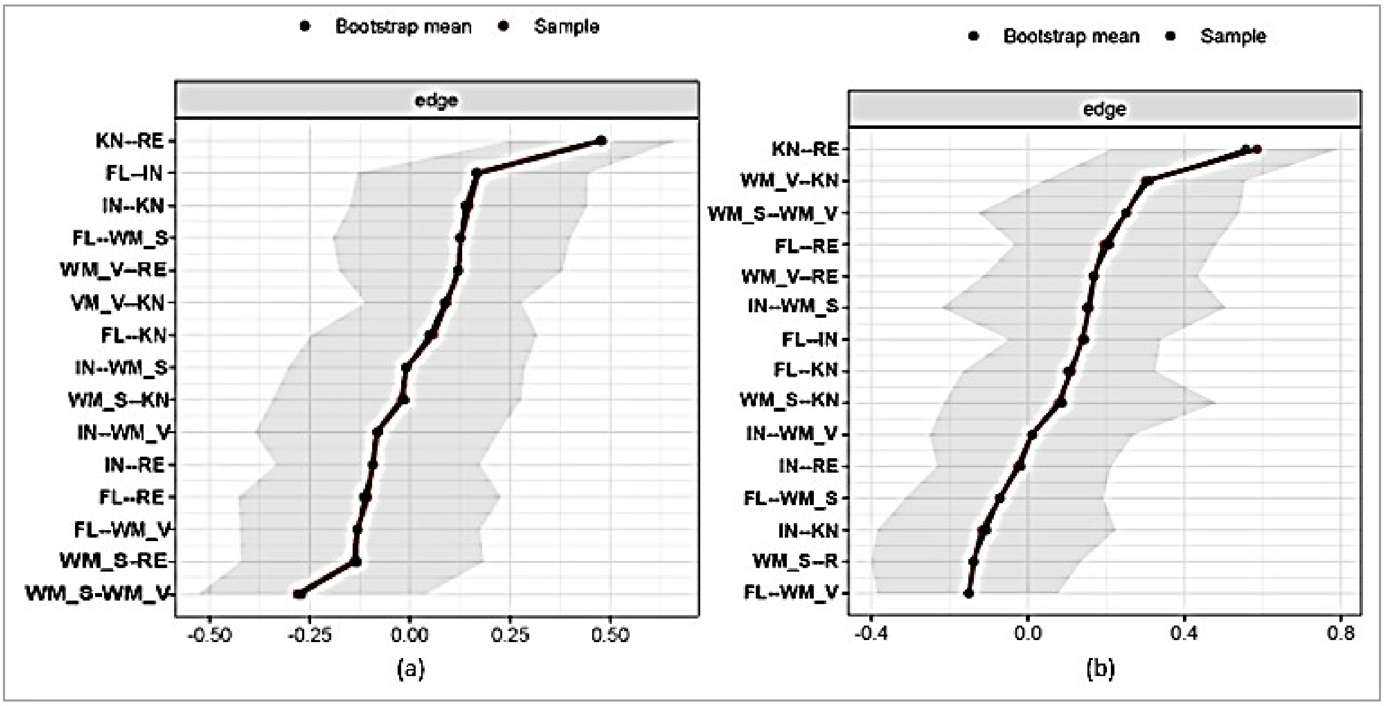
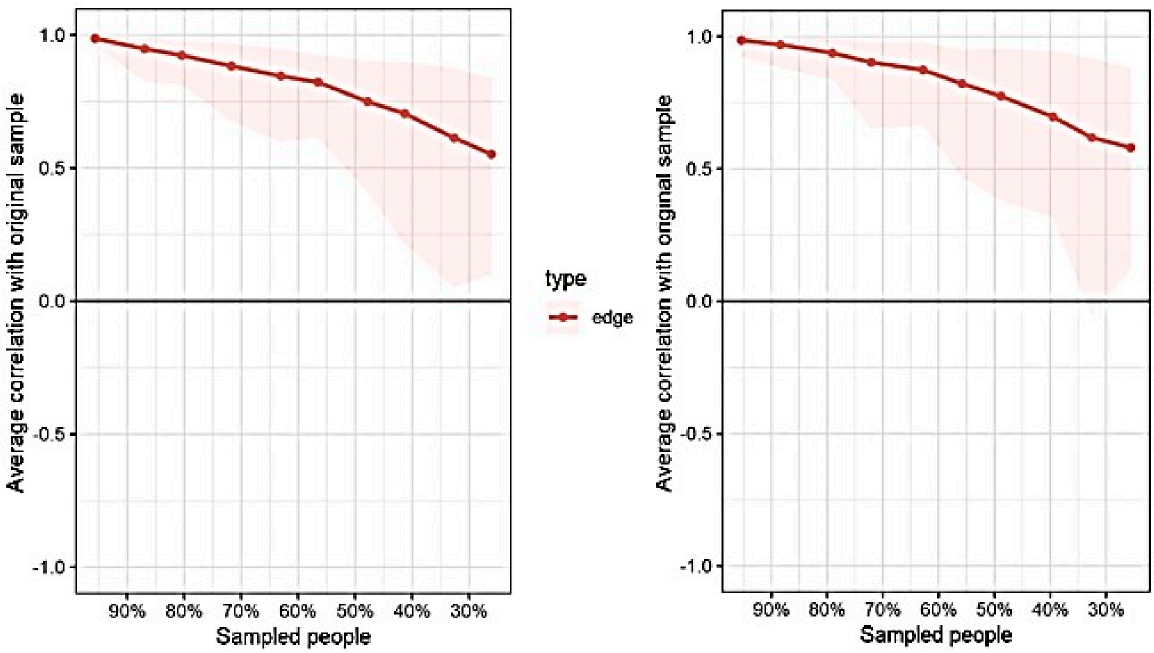


Figure 3. Edge stability for the estimated network. (**a**) Typical; (**b**) HIA. RE = regulation; KN = awareness/knowledge; WM_V = verbal working memory; WM_S = visuospatial working memory; FL = flexibility; IN = inhibition.

As shown, there were several pairs with significant positive effects. However, in agreement with the results described above, the best-connected pair of nodes were awareness and metacognitive regulation in both groups (although the connection was weaker in the typical group). This was followed by metacognitive awareness and the verbal working memory executive component in the group with HIA and the inhibition and flexibility executive components in the group of typical participants. Since most of the estimated edges were greater than zero and were significant (although several estimated 95% CIs contained zero), the precision of the estimated network should be interpreted with caution.

Finally, Figure 4 shows the estimates of the stability of the centrality strength indices for executive functioning and metacognition according to their estimates for the case in which a subsample of the total sample was used.

The values obtained showed that the centrality strength index estimations slowly decreased and remained above 0.70, even when 50% of the sample had been lost, indicating that the study of the stability of the centrality indices was adequate and the estimated network was stable.



(**a**) (**b**)

Figure 4. Edge stability. Centrality strength index stabilities. (**a**) Typical group; (**b**) HIA group.

4. Discussion

The expression of a high intellectual capacity is not immutable but rather, is the product of the covariation between biological, personal, and environmental factors that are dynamically interrelated [39,52]. Among these factors, adequate regulation and application of the skills that facilitate the high neurobiological potential is especially important; having an HIA does not, by itself, imply an elevated level of expertise. All of this corroborates the relevance of the role of regulation of the available intellectual resources and the importance of understanding the relationship between two related constructs: executive functions and metacognition [10,29,53]. These constructs are not always adequately related to each other or measured with the levels of reliability and validity required in the current specialised literature. Research in this field is still in its infancy and in the preliminary stages of clearly and univocally defining each of the components as well as creating measurement tools that can overcome their current "impurity" [14]. Such tools would allow these components to be operationally related to explain the relationships required to facilitate optimal intellectual functioning.

The starting objective of this work was to compare schoolchildren with HIA and those with typical intelligence to understand the relationship between executive functions (and their core components) and metacognition (and its components), as well as the efficacy of these measurements and their relationships. The results of the network analysis we carried out showed the presence of differential intra and inter-domain connections between the components of executive functions and metacognition in both study groups, with these differences being more robust in the group with HIA.

On the one hand, in both study groups, the metacognition construct had the greatest weight with respect to the connections it established, both between its own components and with those of executive functioning. This indicates that metacognition was the most relevant construct in terms of regulating the resources required to build knowledge, create, and learn, thereby corroborating Bellon's postulates [28]. On the other hand, the association between the two components of metacognition (consciousness and metacognitive regulation) was strong in both study groups with respect to the association between the executive components (inhibition, flexibility, and verbal and visual-spatial working memory). This indicates that metacognition may have a greater influence than executive functions on the regulation and application of skills, thus procedurally facilitating the monitoring or control of resources in the resolution of tasks.

The executive components with the most robust connections in the group with HIA were verbal working memory and visual-spatial memory followed by the relationship established between inhibition with flexibility, and the latter one with verbal working memory. In contrast, the relationship between verbal working memory and visuospatial working memory was strongly negative in the typical group, followed by the negative relationship between the latter and metacognitive regulation. Thus, among the typical group, inhibition had the most relationships, although there was no connection between verbal and visuospatial working memory. In the group with HIA, the executive component with the most relationships was flexibility, working memories were strongly connected, and inhibition had less relational weight.

Regarding the relationship between executive and metacognitive components, it should be noted that the weight of metacognitive regulation was greater than that of consciousness, albeit with an intergroup network of differential connections. On the one hand, among the participants with HIA, regulation and flexibility showed the most robust connection, followed by metacognitive regulation with verbal and visuospatial working memories. On the other hand, in the typical group, metacognitive consciousness was best related to the executive components, especially with verbal working memory, and was weakly related to flexibility and visuospatial working memory.

5. Conclusions

In summary, one of the contributions of this current work was our approach to measuring the inter-relationships between executive and metacognitive components. Our data suggest the presence of a differential intra and interdomain network between the study groups, although metacognition was the most determining factor in the relationship between the available resources in both study groups. This may be because procedural and declarative reflection rather than the executive components could provide better guidance on the resources that should be used and their application. Broadly speaking, in the group with HIA, the relationship between executive flexibility and metacognitive regulation predominated, while in the typical group, the relationship between metacognitive awareness and inhibition and verbal working memory stood out. Therefore, differential regulatory networks most likely led to different intellectual functioning, with some connections being stronger than others.

Among the limitations of this work, it should be noted that, although care was taken to carefully measure the executive and metacognitive components using instruments consistent with the processes to be measured, diverse tools were still used. Executive functioning was measured through tasks univocally related to each component being considered, while metacognition was indirectly measured through a questionnaire with proven validity, which allowed us to approximate metacognitive awareness and regulation. Thus, it would be interesting to develop a homogeneous psychological measurement tool for both constructs through tasks with sufficient validity and reliability to be able to contrast future results with these current data. Nonetheless, this work provided results from an alternative analysis method that allowed us to capture the complexity and diversity of the studied constructs and their inter-relationships with a dynamic and multi-causal perspective, and by directly estimating the relationship between all these variables. This could help optimise the debated issue of the impurity of the executive functioning measurement tools and the poor relationship between executive and metacognitive measurements.

Finally, the results we obtained can contribute to operationalising the impact of metacognition and executive functions (and each of their components). This work also contributes to understanding the inter-relationships or integrations of these functions in terms of the perception and use that learners have of their limitations and difficulties. This could perhaps help us to propose a new way to understand the gap between competence and performance, especially in the case of HIA. Making the limitations and strengths in the personal construction of knowledge, creativity, or learning visible can facilitate children's ability to be strategic and may increase their motivation to achieve goals of excellence as well as to transfer their skills to new situations or tasks. Integrating metacognition with executive functioning can facilitate the development of high potential and improve educational interventions by explaining which modulator has the strongest impact on the achievement of the optimal expression of intellectual potential. This corroborates the postulates of Opgong, Shore, and Muis [34], and contributes to explaining the complexity of HIA and its development.

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