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Bridging experimental neuroscience and clinical neuropsychology: Fluid intelligence in frontal lobe assessments

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ABSTRACT

This viewpoint explores the gap between theoretical frameworks in experimental neuroscience and clinical neuropsychology. It highlights how John Duncan's theory of the Multiple Demand (MD) system, which links the frontal lobe to fluid intelligence (g), helps explain general performance on classical executive tests. However, it also discusses how traditional scores often fail to capture the complexity of behaviours associated with frontal lobe damage, and we suggest that developing improved scoring methods could be useful for integrating experimental and clinical neuropsychology insights.

Although the combined efforts of multiple disciplines have led to remarkable advances in understanding frontal lobe functioning, the precise mechanisms by which this brain region facilitates effective behaviours remain unclear. A significant obstacle in understanding frontal lobe functioning is that theoretical frameworks from basic and experimental neuroscience cannot fully account for the diverse clinical deficits observed in patients with frontal lobe damage, which often extend beyond the so-called "dysexecutive syndrome". In this context, advances in cognitive neuroscience have yet to translate into a comprehensive understanding of neurological and psychiatric conditions involving the frontal lobes. Integrating experimental neuroscience with clinical neuropsychology is crucial to addressing this challenge.

John Duncan's theory of frontal lobe functioning proposes that this brain region is a key component of a Multiple Demand (MD) System. Alongside the anterior insula and the intraparietal sulcus, the MD system is believed to encode various types of task-related information (Duncan, 2010). This theory is supported by findings from both animal and human studies, which have demonstrated that neurons within the MD system can adapt to the current task to encode specific information. This conceptualisation explains why the frontal lobe shows activation during a range of cognitive tasks and why damage to this area results in deficits across various cognitive functions.

The crucial role of the frontal lobes in numerous and diverse cognitive tasks naturally led to associating MD activity with the concept of general intelligence (g), first proposed by Spearman in 1904. Spearman introduced the concept of g to account for the universal positive correlations between different cognitive tests. He suggested that a common g factor contributes to success across all cognitive activities. The most effective tests of g, which are highly predictive of general cognitive ability, are fluid intelligence tests. As anticipated, given the known role of the MD system in focusing on task-relevant features, frontal lesions impair performance on traditional fluid intelligence tests; and in normal subjects the MD system is activated during fluid intelligence tests (Duncan et al., 2000). Coherently, in more recent research, g was associated with cortical volume and white matter tract integrity within the MD system (Chen et al., 2021). These findings suggest that fluid intelligence tests measure a fundamental aspect of MD activity.

In parallel, clinical neuropsychology regards the frontal lobes as the neural basis of "executive functions". These executive processes are thought to organise and control cognition and behaviour, and are intrinsic to the ability to respond adaptively to novel situations. Over the past century, numerous clinical tests have been employed to assess these so-called executive functions, such as the Wisconsin Card Sorting Test, Verbal Fluency Tasks, the Trail Making Test, and the Stroop task, which are intended to reflect frontal functioning. These tests are used worldwide in the neuropsychological assessment of millions of patients where multiple neurological and psychiatric conditions are diagnosed or suspected.

The importance of the frontal lobe in fluid intelligence (g), highlighted by experimental neuroscience, has raised questions about the relationship between g and the executive deficits observed in clinical populations. Given that fluid intelligence was expected to correlate

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positively with all tasks, it was reasonable to investigate the extent to which executive deficits could be attributed to a loss of fluid intelligence.

We focused our research on examining the role of fluid intelligence in classical executive tests. The relationship between g and other frontal tasks was first explored in a large population of patients with focal frontal lesions (Roca et al., 2010). We demonstrated that performance on many classical executive tests—such as the Wisconsin Card Sorting Test (WCST) and phonological verbal fluency—was entirely explained by fluid intelligence. For another set of frontal tasks, associated with anterior frontal damage and related to social cognition and multitasking, deficits exceeded those expected from the patients' fluid intelligence loss (e.g. Hotel Task, Reading Mind in the Eyes or Proverbs).

Even if recent case studies have described executive deficits in the context of intact fluid intelligence (e.g. Cipolotti et al. 2022), our results were replicated in many group studies in multiple clinical populations, including frontotemporal dementia, Parkinson's disease, bipolar disorder, schizophrenia, and multiple sclerosis (Roca et al., 2012, 2013, 2014; Goitia et al. 2017, 2020), with the Trail Making Test B added to the list of tests primarily explained by g. In every patient group, the data showed consistent results: deficits measured by classical tests—such as the WCST, verbal fluency, and TMTB—did not seem specific to their cognitive content but rather reflected a more general cognitive decline.

Our findings address the so-called "frontal lobe mystery": some patients with frontal lobe damage who exhibit clear cognitive and behavioural deficits perform remarkably well on classical neuropsychological assessments. In standard neuropsychological evaluations where only classical executive tests are included, deficits associated with the anterior prefrontal cortex are often overlooked.

These results represent a significant advance in the integration of experimental neuroscience and clinical neuropsychology to understand the function of this complex brain area, which underlies the cognitive deficits observed in many neurological and psychiatric conditions.

However, despite the significance of these findings, from a clinical perspective they cast doubt on the clinical usefulness of classical executive tests, whose scores seem to reflect little beyond g.

As emphasised by masters in clinical neuropsychology, from Luria to Lezak, clinical neuropsychology is not merely about scores; it is about creating the right context for behavioural observation. In this regard, the fact that classical scores are explained by g does not undermine the clinical utility of these tests. Instruments such as the WCST, verbal fluency tests, and the TMTB often provide an excellent platform for clinical observation that extends beyond the patient's traditional scores. These tests frequently elicit frontal behaviours that are not captured by the number of categories achieved in the WCST, the number of words produced in verbal fluency tasks, or the time taken in the Trail Making Test or the Stroop task.

Examples of behaviours that are not always reflected in traditional experimental research scores include the Gratton effect observed in Stroop tasks (Gratton et al., 1992) and capture errors in ve rbal fluency tasks (Roca et al., 2018). The Gratton effect, as described in the Stroop task, refers to longer reaction times on incongruent trials following congruent ones (Gratton et al., 1992). The most influential explanation suggests that, following an incongruent trial, suppression of the irrelevant stimulus or task rule is strengthened, leading to faster performance if the next trial is also incongruent. Alternatively, it has been suggested that a congruent trial enhances the processing of irrelevant features, impairing performance on subsequent incongruent trials. On the other hand, "Capture errors" in verbal fluency tasks refer to a form of behavioural interference that occurs when a previous rule –generating words with the letter "f" – is re-activated in the semantic fluency task when by chance an answer coherent with both rules is produced (e.g. naming animals exclusively beginning with the letter "f" or even return to the old rule, generating words beginning with "f" not matching the required semantic category). Though in this kind of error we are dealing with a somewhat different type of interference occurring between successive tasks, similar underlying control mechanisms seems to be involved. Although these behaviours, among others, may not necessarily impact conventional test scores, their clinical significance and potential should not be overlooked.

Whether by focusing on alternative scoring methods, designing tasks that specifically tackle such abnormal behaviours, or leveraging new technologies that allow us to identify more subtle and frequent forms of interference (e.g., latency patterns following trials with congruency-based errors between the current and previous tasks), clinical neuropsychology should provide alternative data to be used in experimental neuroscience.

Additionally, to improve research frameworks, experimental neuroscience must actively reach out to clinical neuropsychology to design experimental paradigms aimed at disentangling the behaviours observed in clinical cases.

Undoubtedly, building such bridges between both disciplines would allow for a faster and deeper understanding of brain functions, particularly those of the frontal lobe.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT in order to improve the readability and language of the manuscript and organization of the references. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

CRediT authorship contribution statement

María Roca: Writing – review & editing, Writing – original draft, Conceptualization. **Facundo Manes:** Writing – review & editing.

Data availability

No data was used for the research described in the article.

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