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LETTER TO THE EDITOR

Reply: Lack of statistical significance is not evidence against modularity in visual feature processing

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We are delighted by the engagement that Griffis and Boes[1] have shown with our study,[2] and we see this as a perfect example of how open access to data advances scientific discourse. Having full access to the data and results, not merely the paper, adds a dimension that enables researchers to go beyond simply citing conclusions to actually examining the underlying evidence. We hope that this type of data-driven dialogue will accelerate our understanding of what results truly imply, moving beyond 'our data shows this, your data shows that' discussions.

Their critique highlights a fundamental tension in the field between two interpretations of what we tested and what our findings reveal about visual organization or perhaps reflects our failure to communicate this clearly. While they focus on whether weak statistical associations exist, we tested whether the strong claims of modular theory—that specific areas are functionally essential for particular features—hold up under systematic examination. We therefore welcome this opportunity to clarify our theoretical framework and empirical approach.

The nature of strong modularity claims

Griffis and Boes[1] suggest we should have performed targeted region-of-interest (ROI) analyses of V4 and MT to test modularity. This recommendation highlights an important conceptual distinction that we perhaps did not articulate clearly enough: what strong modularity theories actually claim about visual processing. Visual modules, as theorized by Fodor[3] and empirically grounded in Zeki's pioneering work on V4,[4] and MT,[5] represent functionally critical processors, not merely regions with preferential responses.

While Fodor himself focused on abstract computational modules rather than specific anatomical regions, the visual neuroscience community has extensively applied his modular framework to these brain areas. The resulting theory proposes them as functionally critical processors—regions whose damage should reliably produce selective deficits because they perform computations that cannot be adequately compensated by other areas. This distinction between 'functional necessity' and mere 'regional associations' is not semantic but reflects fundamentally different claims about brain organization.

The strong modularity framework thus makes testable predictions: if V4 and MT are truly essential for colour and motion perception, damage to these regions should produce consistent, robust, and relatively selective deficits—effects that would emerge clearly in systematic analyses without requiring special analytical treatment.

Our successful replication of V1-visual field relationships ($z > 6.0$) guided our approach. These truly critical brain–behaviour relationships emerged robustly in whole-brain analyses, suggesting that if similar functional dependencies existed for mid-level features, they should be similarly detectable. The fact that they were not—despite adequate power to detect other predicted relationships—raises important questions about the modular framework itself. Rather than supporting modularity, examination of our data reveals systematic contradictions to modular predictions across multiple levels of analysis.

Individual patients contradict criticality claims

Direct examination of individual cases reveals a pattern incompatible with functional specialization criticality. Among nine patients with documented MT damage, only four exhibited motion perception deficits—meaning that 56% maintained intact motion perception despite lesions to this supposedly essential region. Conversely, our sample included 25 patients with motion deficits overall, yet the vast majority (84%) of these impairments occurred without MT involvement, demonstrating that motion processing deficits

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arise through diverse mechanisms beyond damage to the putative motion module. If MT were truly the critical computational hub for motion as modular theories claim, we would expect near-universal deficits following its damage—not preservation of function in most cases. This pattern directly contradicts the core prediction of functional necessity that defines a visual module.

These observations constitute direct empirical contradictions rather than statistical nuances. If MT were computationally necessary for motion perception, as modular frameworks claim, we should observe near-universal deficits following MT damage. Instead, preserved function in most MT-damaged cases, combined with widespread motion deficits occurring without MT involvement, reveals a fundamental mismatch between theoretical predictions and clinical reality—one that cannot be resolved through appeals to statistical power or methodological refinements.

Peak effects localize to unexpected regions

Griffis and Boes[1] correctly note that our unthresholded maps show associations between brain damage and visual deficits. However, these effects peak in regions (entirely) different from those predicted by modular theories (Fig. 1). The pattern is striking in its consistency: colour deficits peak in parahippocampal regions ($z = 3.48$) rather than the supposedly critical V4; motion deficits localize most strongly to temporo-parietal junction areas ($z = 3.87$) rather than MT/V5; and contrast deficits peak in frontal regions ($z = 4.01$), despite having no designated module in traditional frameworks.

This spatial mismatch cannot be dismissed as a power issue. Even without statistical correction, the brain regions showing the strongest associations with visual deficits are not the regions that modular theories identify as functionally critical.

Systematic pattern across all features

The absence of strong localization extends systematically across all eight visual features we tested, revealing a pattern that challenges the theoretical foundations of modularity. Colour and motion—the flagship examples of modular organization with decades of research supporting their specialized processing in V4 and MT—show no stronger regional associations than features like texture or glossiness, which lack any comparable theoretical framework or proposed neural modules.

This uniformity is particularly striking given the vastly different levels of theoretical investment and empirical study across these features. If modular organization reflected a fundamental principle of visual processing, we would expect at least the most intensively studied and theoretically established examples to show clear regional specialization. Instead, the equivalent weakness of localization across all features—regardless of their theoretical status—suggests that mid-level visual processing operates through distributed networks that do not respect the categorical boundaries that have structured decades of research.

The adequacy of our sample

Griffis and Boes[1] raise concerns about statistical power, but our sample of 307 patients with systematic visual testing exceeds most landmark studies in this field. For comparison, the influential studies establishing V4-colour and MT-motion associations relied on single cases.[6,7] Our null findings from a sample orders of magnitude larger cannot be dismissed as underpowered when the field has accepted positive claims from drastically smaller samples.

Why targeted region-of-interest analyses would be inappropriate

Griffis and Boes[1] advocate for confirmatory ROI analyses targeting V4 and MT. While we understand the appeal of this focused approach, we believe it would introduce methodological problems that obscure rather than clarify the nature of visual organization.

Testing only theoretically favoured regions assumes the validity of the framework we seek to evaluate. Our whole-brain approach revealed that peak associations for visual deficits consistently localize to regions outside traditional modular predictions—parahippocampal areas for colour, temporo-parietal regions for motion. A targeted analysis restricted to V4 and MT would have missed these patterns entirely, potentially confirming prior assumptions while overlooking the actual distribution of brain–behaviour relationships.

Moreover, genuinely critical brain–behaviour relationships should not require a ROI analysis to detect. The V1-visual field relationships we replicated emerged with remarkable clarity ($z > 6.0$) through standard whole-brain analysis, without targeted approaches or relaxed thresholds. If V4 and MT held comparable functional importance for colour and motion processing, we would expect similarly robust effects. The need for specialized analytical strategies to detect these relationships suggests they may be weaker and more contingent than modular theories propose.

Most fundamentally, selective regional analysis risks transforming hypothesis testing into hypothesis preservation—what Meehl[8] identified as the methodological paradox of protecting theories through increasingly specific auxiliary assumptions. By examining only regions chosen based on existing theoretical commitments while excluding contradictory evidence from elsewhere in the brain, such approaches can perpetuate frameworks regardless of their empirical adequacy. Science advances through comprehensive evaluation of theoretical predictions, not through methods designed to confirm them.

Moving forward

Griffis and Boes' thorough analysis has sharpened our interpretation and highlighted the implications of these results. The question is not whether targeted analyses can find statistical associations, but whether the overall pattern supports modular organization. It does not.

We stand by our findings: the evidence reveals a systematic pattern incompatible with modular predictions: damage to supposedly critical areas fails to produce the consistent deficits that functional necessity requires, while these same deficits routinely emerge from diverse lesion locations. This dissociation—preserved function despite damage to putative modules, coupled with deficits arising through multiple alternative mechanisms—points to distributed processing as the most empirically adequate explanation. While modular theories require auxiliary assumptions to accommodate these findings (backup pathways, incomplete lesions, compensatory mechanisms), distributed organization predicts exactly this pattern without additional theoretical commitments. Following the principle of inference to the best explanation, the framework that naturally accounts for the observed data without *post hoc* modifications provides the most compelling account of visual organization.

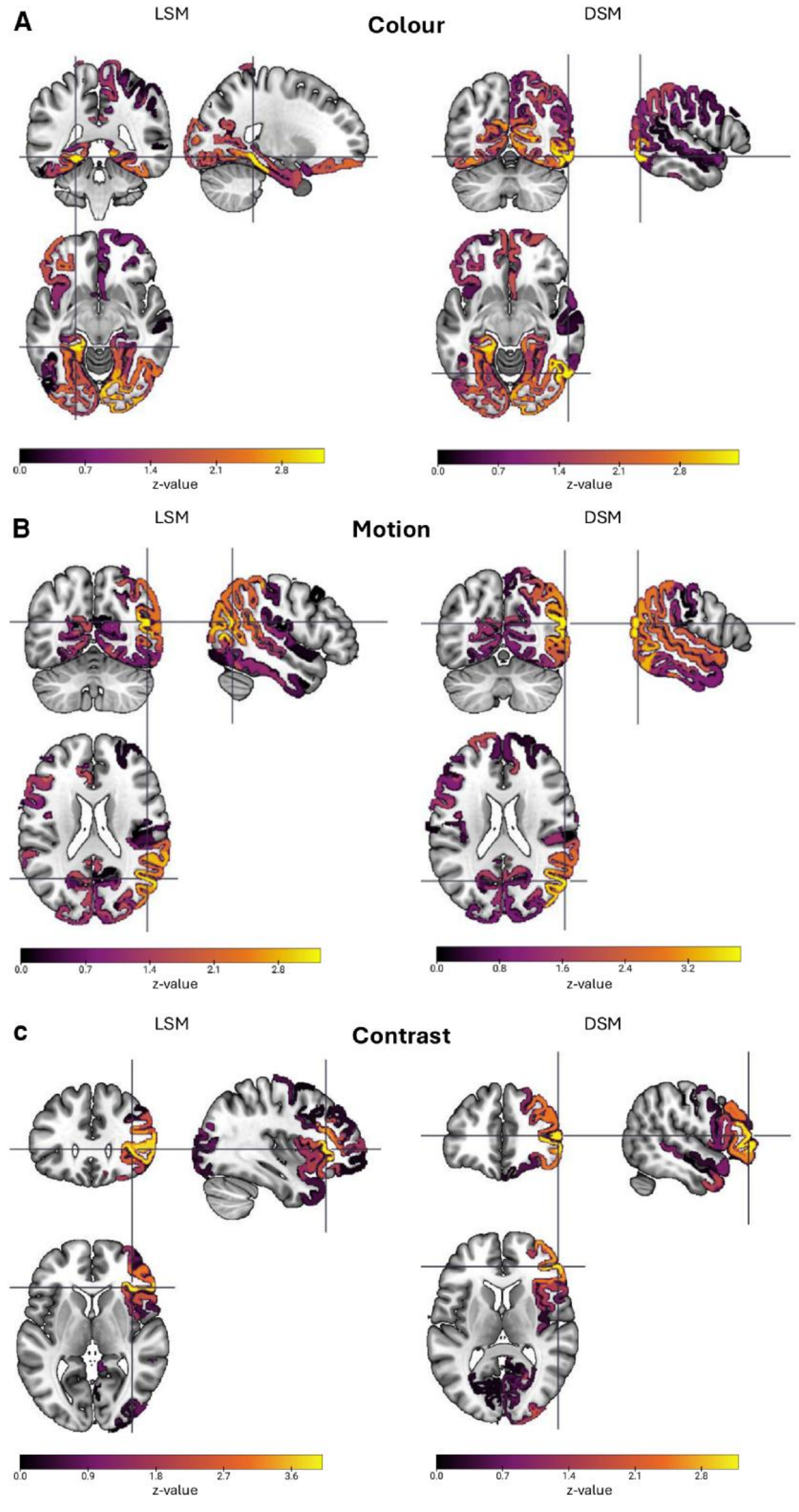

Figure 1 Peak effects systematically contradict modular predictions: evidence localizes to regions with no proposed specialization. Unthresholded statistical maps from lesion-symptom mapping (LSM, *left*) and disconnection-symptom mapping (DSM, *right*) analyses. (**A**) Colour deficits peak in parahippocampal regions, not V4. (**B**) Motion deficits peak in temporo-parietal areas, not MT/V5. (**C**) Contrast deficits peak in frontal regions, despite having no proposed module. Even without statistical correction, the strongest associations systematically contradict modular predictions.

This reconceptualization has immediate clinical implications. Current neuropsychological assessments assume orthogonal factors in mid-level vision (colour, motion, shape as independent dimensions), leading to tests that may be hampered in eternal validity miss the actual nature of visual deficits by testing features that the brain never processes in isolation. We advocate developing assessments based on the statistical structure of natural visual environments—testing how patients process naturally co-occurring feature combinations rather than isolated attributes. Such assessments would not only better capture real-world visual function but could also reveal previously hidden patterns of impairment and recovery potential. As detailed in our theoretical framework,[9] understanding visual processing as organized around natural feature constellations opens new directions for both research and clinical practice that better align with how vision actually works.

Data availability

The data that support the findings of this study are openly available on Open Science Framework (OSF) at osf.io/yq93s in the directory Response_Griffis_and_Boas.

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Competing interests

The authors report no competing interests.

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