# Individual differences in shared representation of symbolic and nonsymbolic number at 7T fMRI

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## Introduction

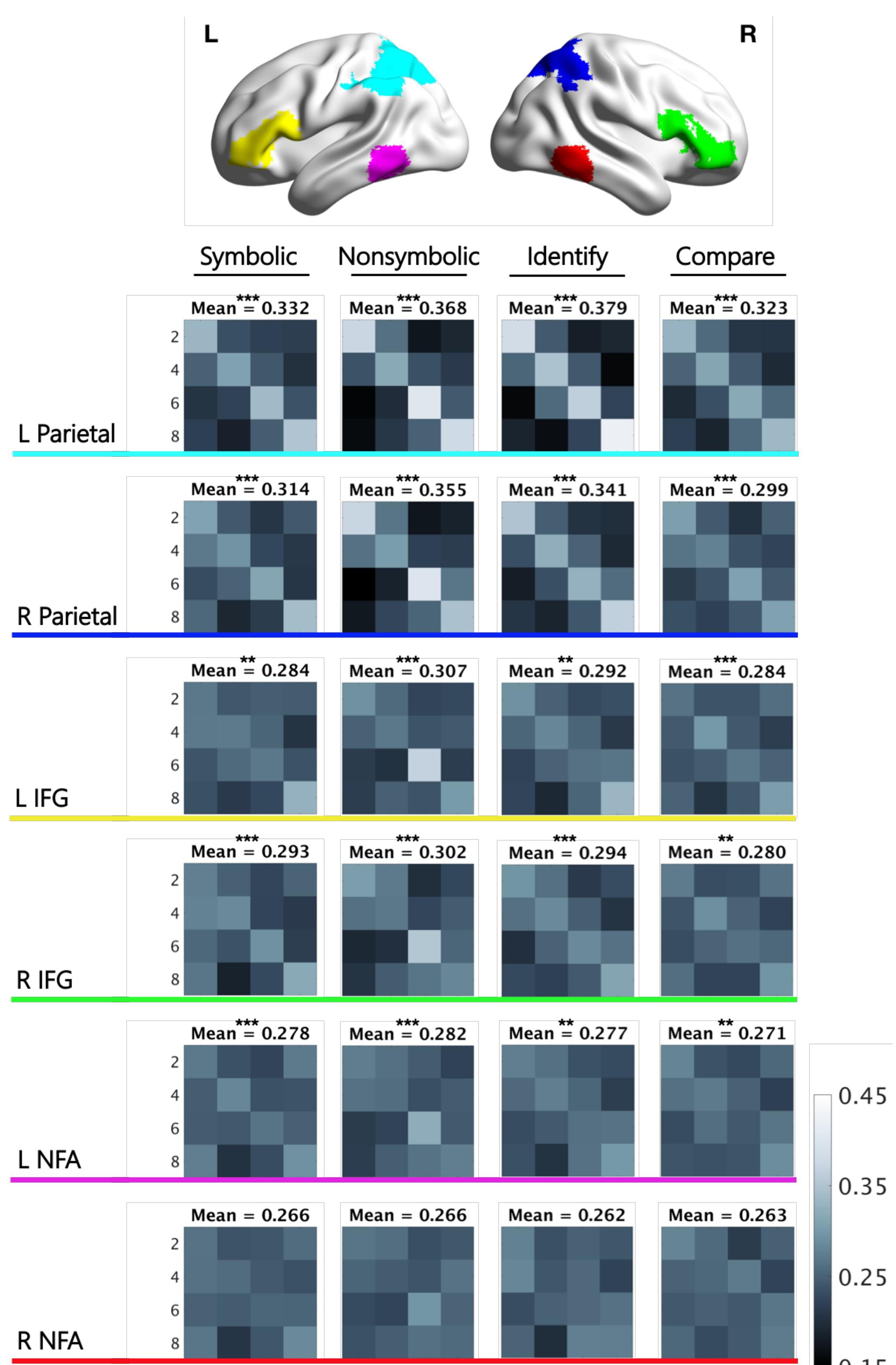
- Debate continues whether the encoding of symbolic number is grounded in nonsymbolic numerical magnitudes,[1] is independent,[2] or is linked early in development but then decoupled over time.[3]
- Regardless, fluency of perceiving both number formats, and translating between them, is associated with math skills across the life span.[4-6]
- However, what drives the correlation between number processing and math skills is not well understood.[7]
- The current study uses MVPA of task-based fMRI to investigate the neural representation of number across formats (nonsymbolic & symbolic) and tasks (comparison & identification), and further, how individual differences in these representations relate to behavior.

## Research Questions

1. Do symbolic and nonsymbolic representations of number share cortical patterns of activation?
2. Are representations of number task-dependent?
3. Do patterns of neural response to number (i.e. decoding performance and between-format generalization) relate to behavioral metrics of numerical ability, measured by:
   (a) number comparison in both number formats
   (b) mathematics achievement

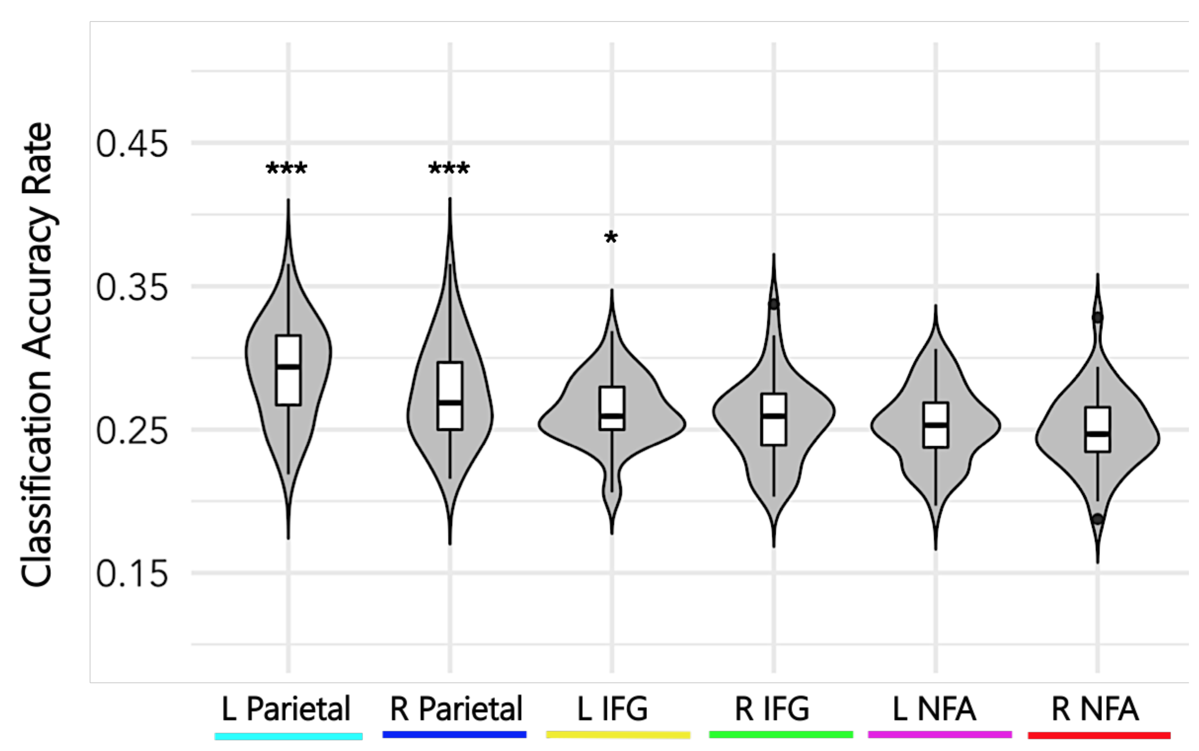
## Results

Decoding Performance

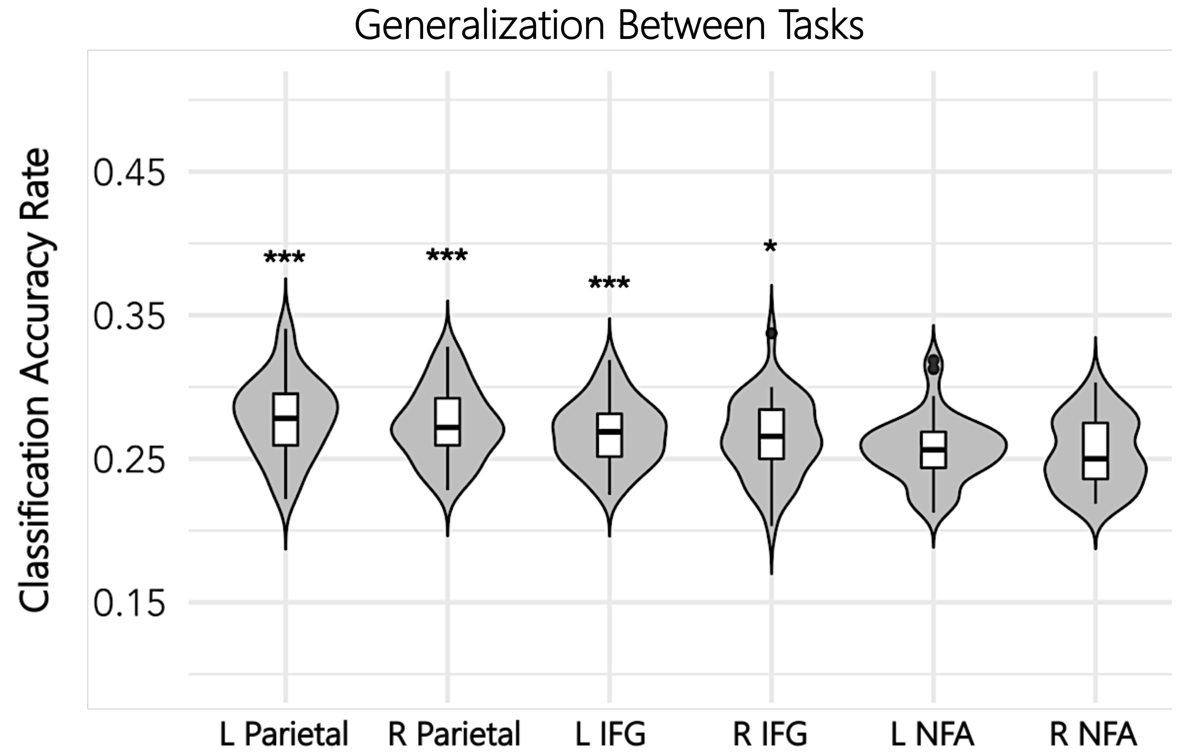



* $p$ < .05, ** $p$ < .01, ***$p$ < .001

Generalization Between Formats




Generalization Between Tasks

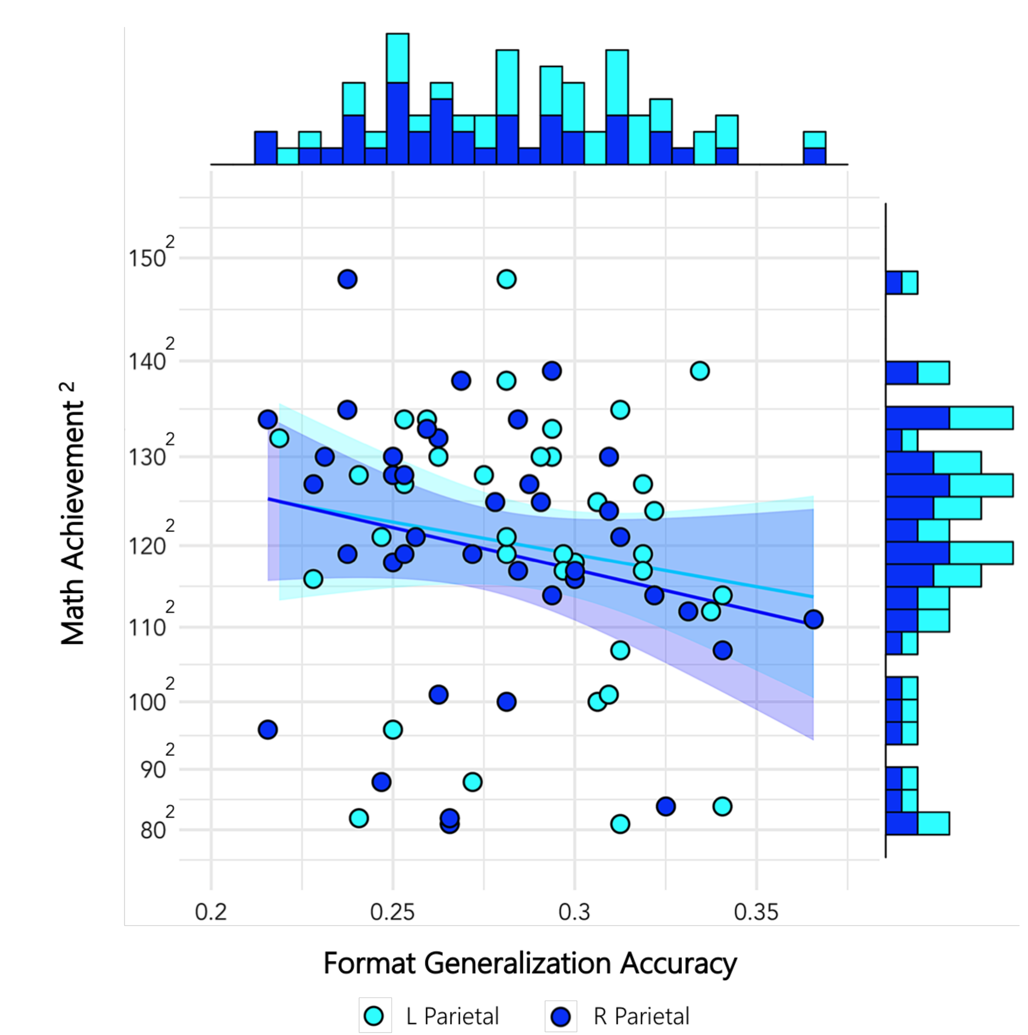



Correlations Between Decoding & Task Performance

| | | Decoding Accuracy Rates | | | | | |
|---|---|---|---|---|---|---|---|
| **Task Performance** | | L Par | R Par | L IFG | R IFG | L NFA | R NFA |
| Nonsymbolic Comparison P | Pearson r | .073 | .093 | -.013 | -.103 | -.04 | .053 |
| Nonsymbolic Comparison w | Pearson r | .066 | -.054 | .101 | .083 | -.014 | -.124 |
| Symbolic Comparison P | Pearson r | -.185 | -.156 | -.156 | -.217 | -.018 | .018 |

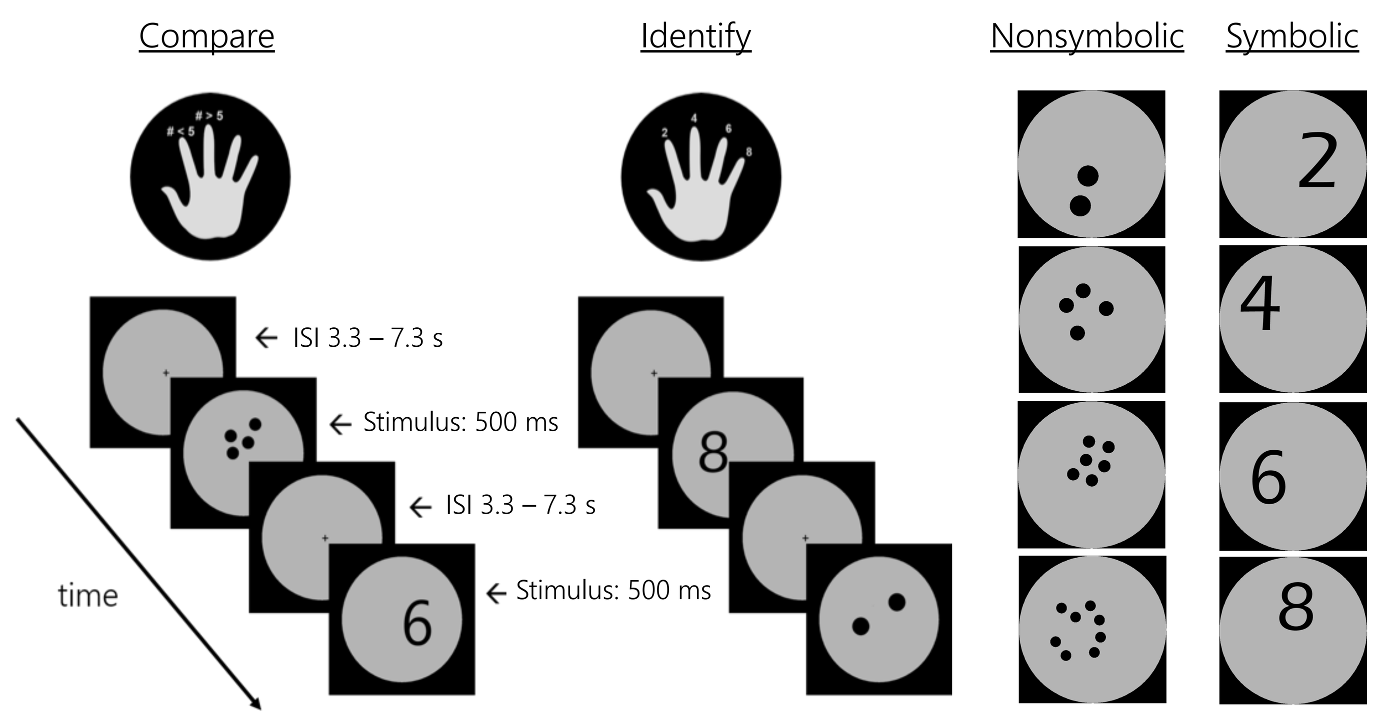
Correlation Between Format Generalization & Math Achievement

- L Parietal Spearman *rho* = -.267, $p$ = 0.050
- R Parietal Spearman *rho* = -.319, $p$ = 0.024




## Methods

- **Participants:** $n$ = 39, *Mean* age = 19.8 (18.4 – 22.3), 20 females.
- **Procedure:** *Session 1:* cognitive measures including symbolic and nonsymbolic number comparison, Calculation and Math Fluency (WCJ-III). *Session 2:* completed "identify" and "compare" task. *Identify*: judge if presented Hindu-Arabic digit (Symbolic) or dot array (Nonsymbolic) is 2, 4, 6, or 8. *Compare:* same stimuli, indicate whether number is less than or greater than five.
- **Task:** event-related design; intermixed symbolic/nonsymbolic; 160 trials per task (80 each format, 20 per number per task).
- **MRI:** 7 T Philips Achieva, 32ch head coil; MP2RAGE – 1mm$^3$; T2* - 2.5mm$^3$, TR 2s, two runs, total 16m40s of fMRI data




- **Analysis:** Per-trial beta maps estimated with AFNI's 3dDeconvolve. Decoding/generalization classification implemented in MATLAB using the linear discriminant analysis classifier in CoSMo MVPA toolbox[8]. Leave-3-out, cross-validation for decoding. Classification results were tested for significance (p < .05) across participants with two-tailed t-test, testing against the null of a chance-level classification (25%, given 4 numerosities). Results are Bonferonni-corrected. The same procedures were used to test generalization from one format and task to the other, except the classifier was trained on all samples of one condition and tested on all samples of the other.

## Discussion

- Decoding was above chance in the bilateral parietal ROIs, IFG, and left NFA, indicating the encoding of number-specific information in these regions.
- The classifier generalized from symbolic to nonsymbolic (and reverse) in L and R parietal ROIs and left IFG, indicating numerosity-specific neural resources are shared between formats.
- Generalization was successful across tasks, suggesting task-independent number processing.
- In contrast to Lasne et al. decoding performance did not relate to number comparison performance or math ability,[9] but generalization between formats did relate to math achievement, similar to Bulthé et al.[10] The current findings suggest within-format precision of numerosity does not link basic number processing and math skills. However, the relation between nonsymbolic and symbolic number is of relevance.

## References & Acknowledgements

**References:** **1.** Piazza, *TICS*, 14, 542–551 (2010). **2.** Carey & Barner, *TICS , 23, 823-835* (2019). **3.** Lyons et al., JEP: Gen. 141, 635–41 (2012). **4.** Fazio et al. *JECP*. 123, 53–72 (2014). **5.** Schneider et al. *Dev. Sci*. 20, e12372 (2017). **6.** Price & Wilkey. *Cogn. Dev*. 44, 139–149 (2017). **7.** Wilkey & Ansari. *NYAS*. 1464 (1), 76-98 (2020) **8.** Oosterhof et al. bioRxiv 10, 047118 (2016). **9.** Lasne et al., *Cortex*. 1–12. 114, 90-101. **10.** Bulthé, et al., *Cortex*, 101, 306–308. **Acknowledgements**: This work is supported by NSF grants 1660816 and 1750213 to GRP. EDW is the recipient of a Banting Postdoctoral Fellowship (NSERC) and BrainsCAN Postdoctoral Fellowship at Western University, funded by the Canada First Research Excellence Fund (CFREF). **Correspondence to**: Dr. Eric D. Wilkey <ewilkey@uwo.ca>