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## Fast comprehension of geometrical primitives and rules in human adults and preschoolers

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## INTRODUCTION: ARE HUMANS ENDOWED WITH A GEOMETRICAL LANGUAGE?

❖ Studies of sequence learning have outlined one possible mechanism by which complex mental representations are constructed out of simpler primitives: the human ability to **extract complex nested structures from sequential inputs**.

❖ Experiments in infants, preschoolers, and adults without

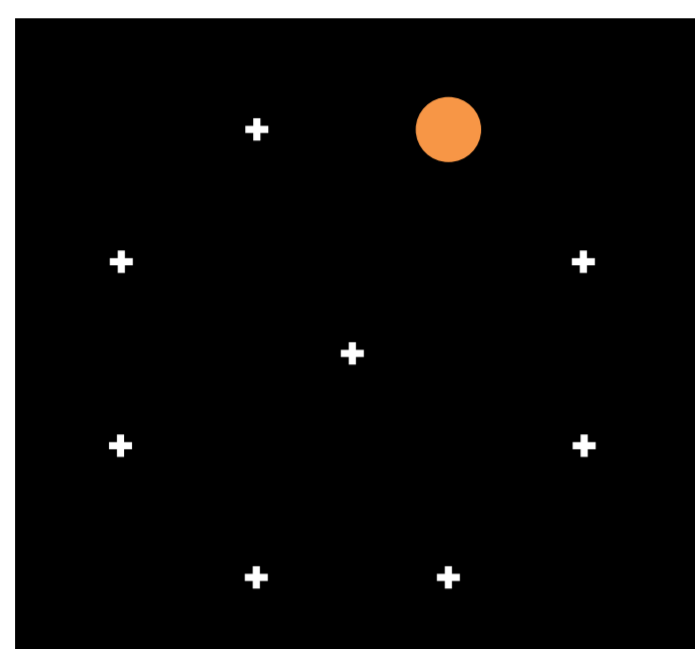
access to education have demonstrated the existence of innate **“core knowledge” for space**, endowing humans with spontaneous intuitions of geometry.

❖ The question therefore arises whether a capacity for the internal representation and manipulation of nested

sequences also underlies the acquisition of mathematics.

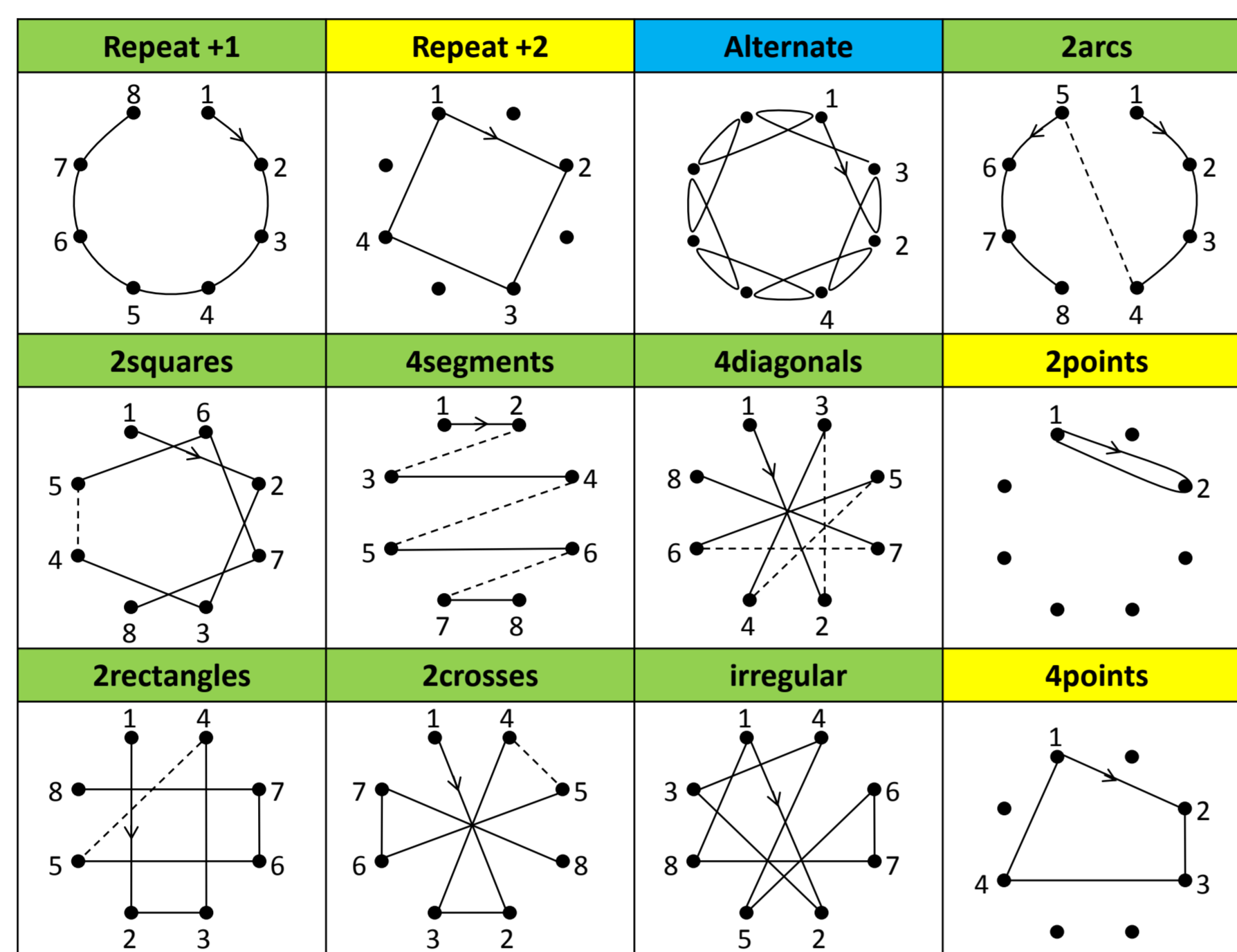
❖ We propose to formalize the human sensitivity to mathematical rules through a **“language of thought”** that allows the formation of complex representations from a small repertoire of primitives.

## METHOD: COMPLETION TASK



Subjects saw the first locations of a given sequence and had to point to the next ones. If they were mistaken, the sequence restarted.

**Participants:**  
23 French adults and 47 5-years-old children, and 14 Mundurucu teenagers and adults.

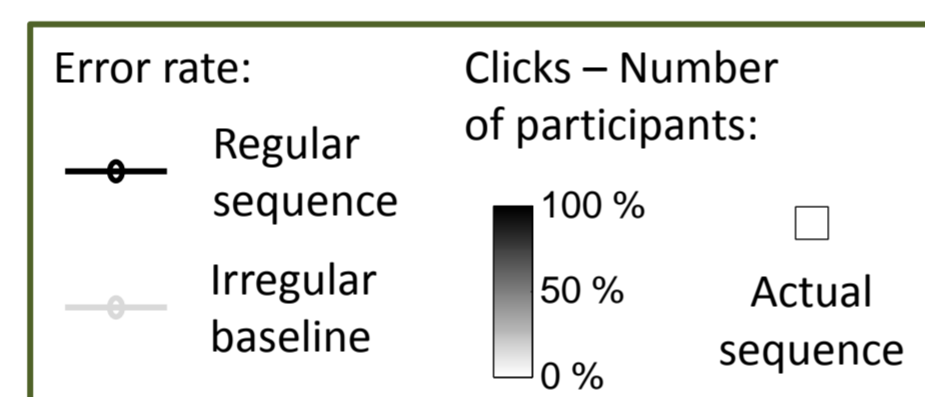
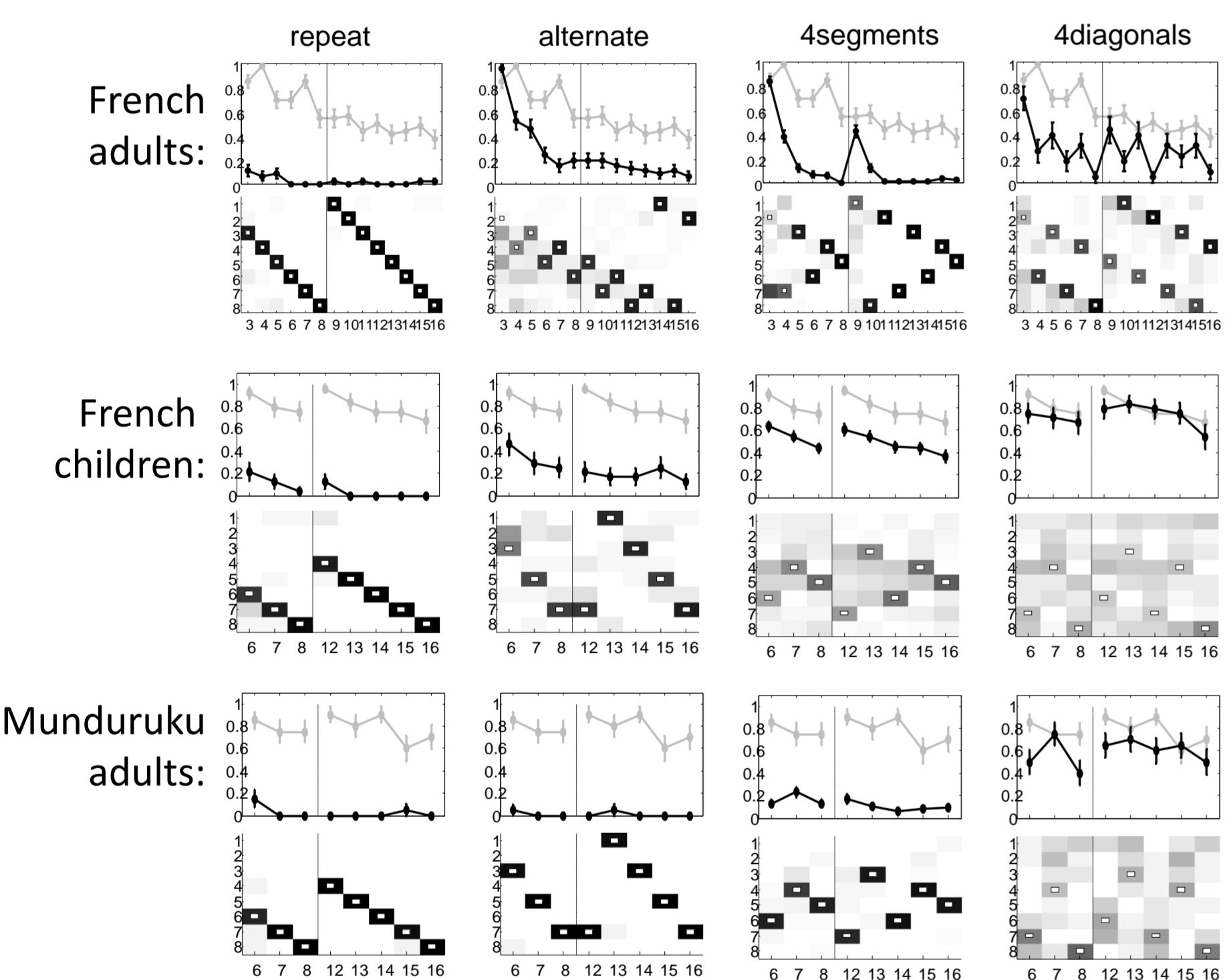


## GEOMETRICAL LANGUAGE

		<b>Repeat +1</b> 01234567 K=5 [+0, [+1] <sup>7</sup> ]	<b>Repeat +2</b> 02460246 K=5 [+0, [+2] <sup>7</sup> ]
		<b>Alternate</b> 0213243546 K=8 [+0, +2] <sup>8</sup> {+1}	<b>2arcs</b> 01237654 K=8 [[+0, [+1] <sup>3</sup> ] <sup>2</sup> <V>]
<b>2squares</b> 02467135 K=8 [[+0, [+2] <sup>3</sup> ] <sup>2</sup> <-1>]	<b>4segments</b> 01726354 K=7 [[+0, H] <sup>4</sup> {-1}]	<b>4diagonals</b> 04152637 K=7 [[+0, P] <sup>4</sup> {+1}]	<b>2points</b> 02020202 K=7 [[+0, +2] <sup>4</sup> {+0}]
<b>2rectangles</b> 05416327 K=10 [[+0, -3] <sup>2</sup> {P}] <sup>2</sup> <-2>]	<b>2crosses</b> 04512673 K=7 [[+0, P] <sup>4</sup> {-3}]	<b>Irregular</b> 04715236 K=16 [+0, P, B, +2, P, B, +1, H]	<b>4points</b> 02360236 K=11 [[+0, +2, +1, +3] <sup>2</sup> <+0>]

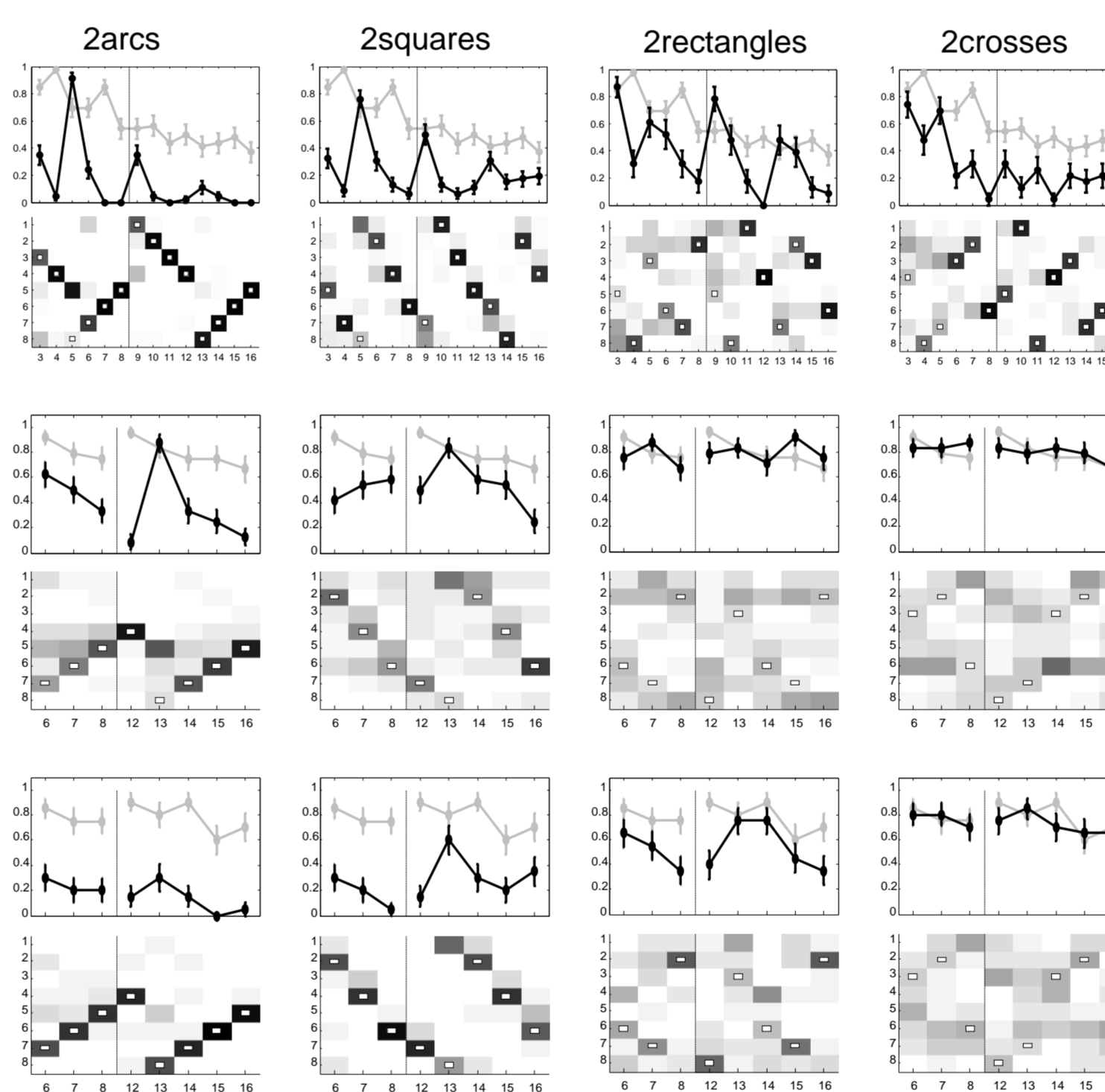
## RESULTS

### Knowledge of geometrical primitive rules

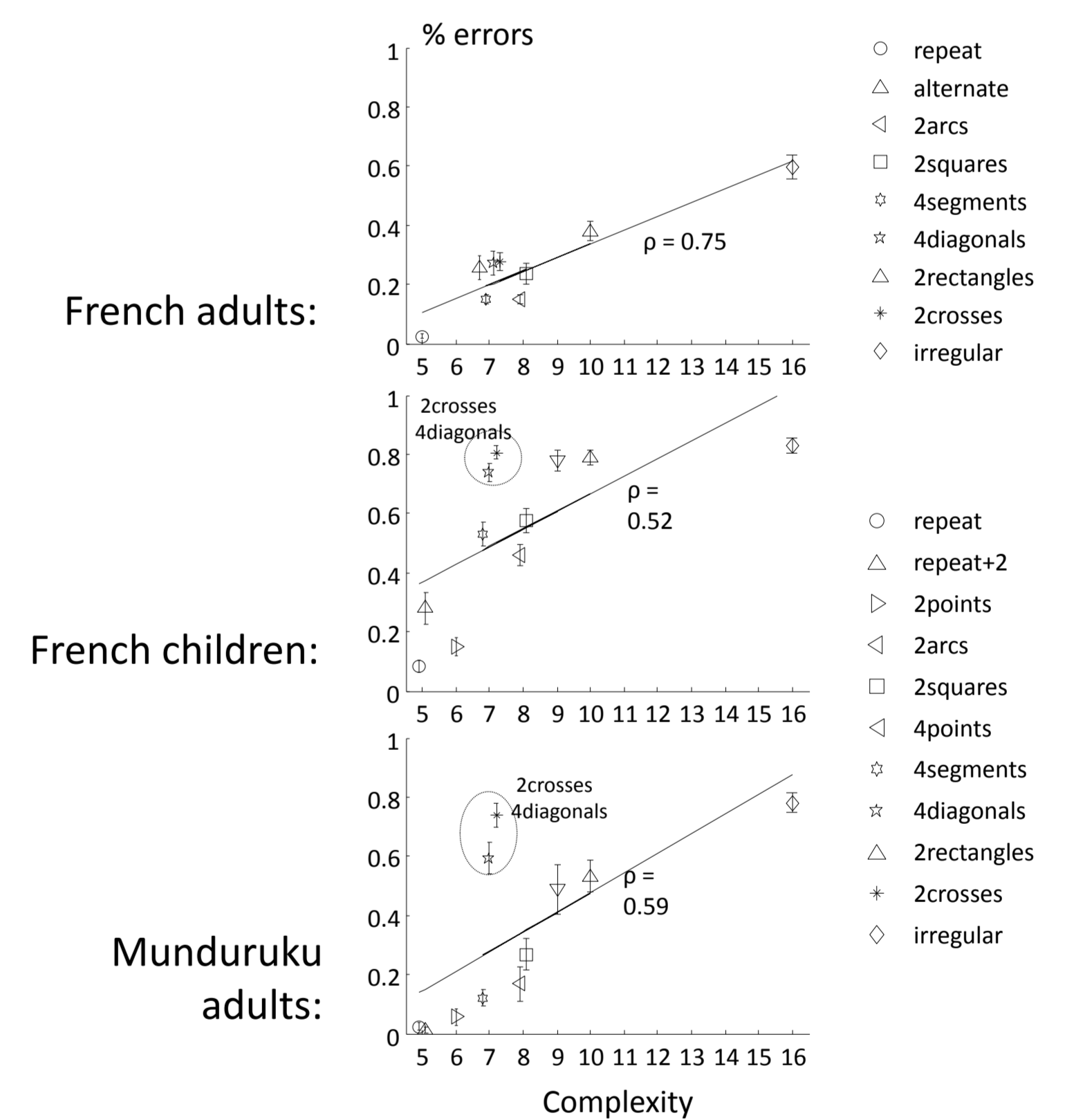


➤ In comparison to irregular baseline, most of the regular sequences were well learnt.  
➤ Error pattern directly reflects the hierarchical internal representation of sequences.  
➤ Error rate at specific data point indicates how well a given rule is understood: e.g. in “4segments”, even data points reveal that all axial symmetries are detected by all groups of participants.

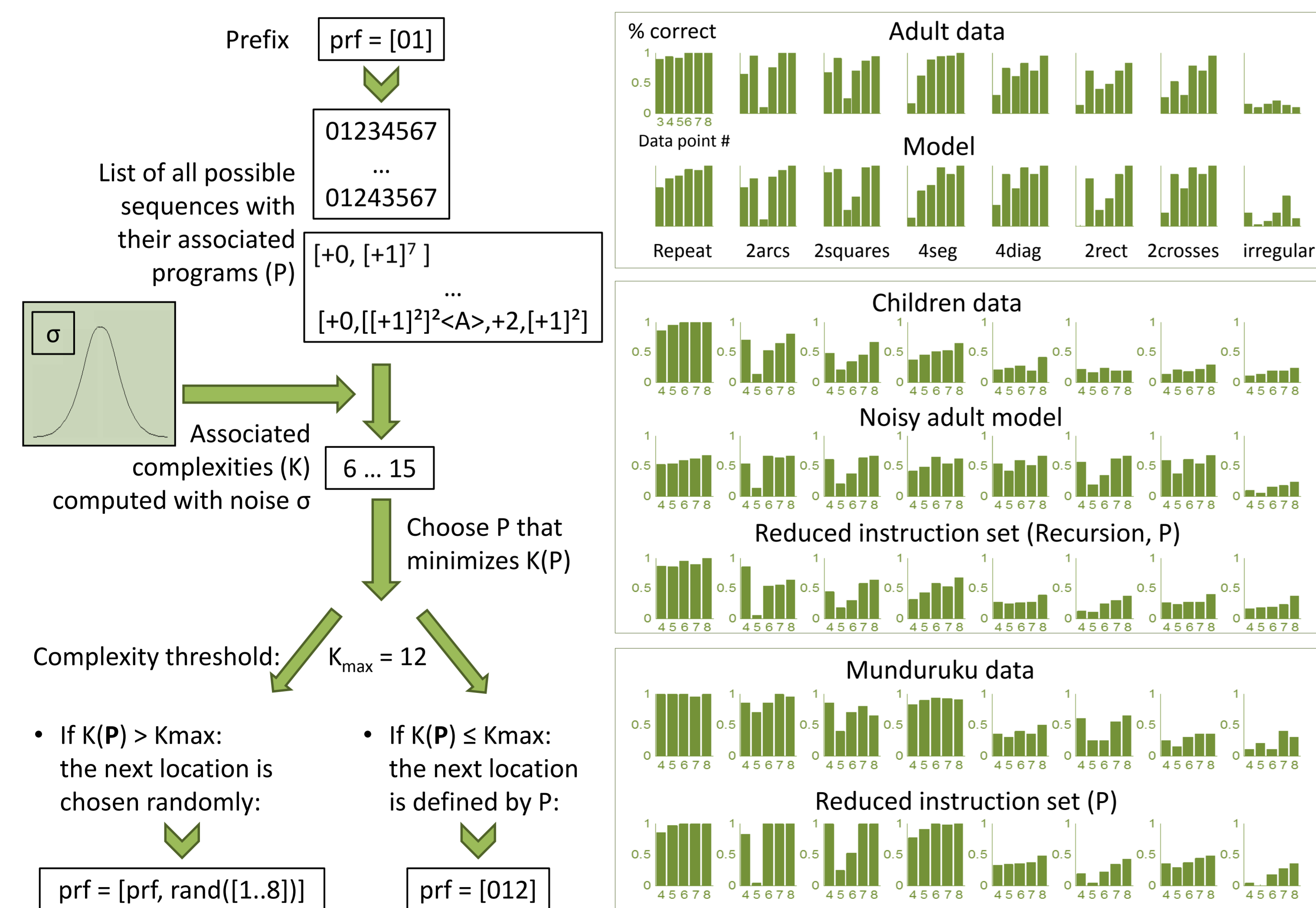
### Learning of embedded rules



### Kolmogorov complexity well predicts subjects' performance



## MODEL FITS



## CONCLUSIONS

- **Simple rotations and axial symmetries were all detected** and quickly used by human adults and 5-years-old children. Point symmetry was more challenging for French preschoolers or Mundurucu adults than for French adults.
- Human subjects were able to detect most of the embedded expressions we used to define our visuospatial sequences such as simple repetition, concatenation, and some repetition with variation.
- **The analysis of error patterns provided direct evidence for hierarchical embedding:** superficial rules were acquired more quickly and induced fewer errors than deeper rules.
- **With age, a geometrical language endowed with nested rules seems to arise even in the absence of formal schooling,** as Mundurucu adults who lacked school-based education, performed better than 5-years-old kids.
- In children, the failure with complex sequences could arise from limitations in working memory and not necessarily to a lack of understanding nested structures.
- **The theoretical complexity of a sequence was an excellent predictor of its mean error rate,** and we confirm that minimal description length is a reasonable approach of adult sequence learning capacity.
- Additional primitives, both geometrical and non-geometrical still need to be added to our model to complete its description of “core geometry”.

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