Neural Development of Phonological Working Memory: Interplay between Language and Memory Systems

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INTRODUCTION

Phonological working memory (PWM)
- PWM is the ability to maintain and manipulate sequences of speech sounds.
- PWM plays a crucial role in comprehension and production.
- PWM reflects lexical knowledge and affects word learning (Zamuner et al., 2004; Gathercole et al., 1999)

Non-word Repetition (NWR)
- NWR taps into children's ability to process, store and repeat verbal information in speech.
- NWR is an effective clinical assessment for PWM.
- Impaired NWR is a behavioral hallmark of developmental language disorders.

Research Questions
Does the maturation of PWM reflect the development of speech and language functions or domain-general memory systems?

TASK

"CRIMIPISM" "CRIMIPISM" SCAN "TECTOR" "TECTOR" SCAN

TA = 6 sec · 2 sec
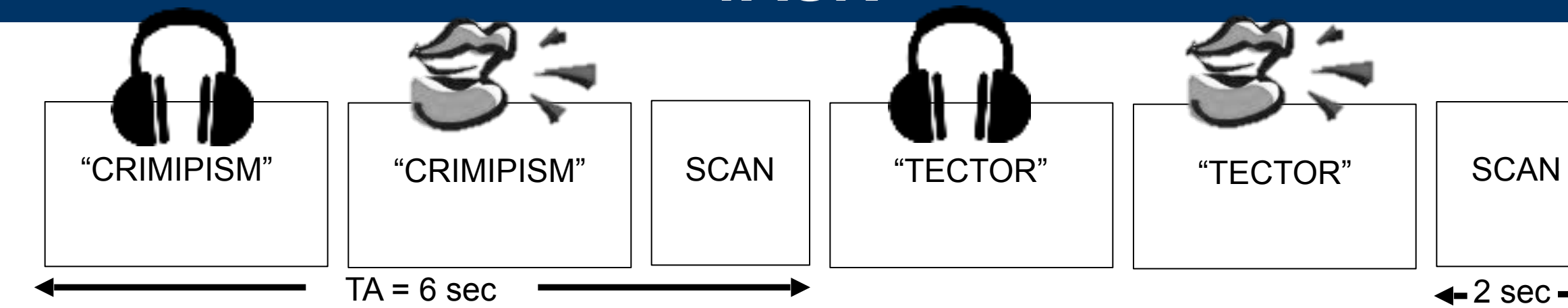
Stimuli: 96 nonwords, phonetically matched to English, are evenly distributed in four PWM loads (2, 3, 4 and 5-syllable long).
Procedure: 32 task trials randomly interspersed with 8 resting trials in each run for 3 runs. Participants listen to and repeat nonwords in the scanner.

IMAGING ACQUISITION AND ANALYSIS

- **Acquisition**
  Siemens Trio 3T MRI scanner, 32-channel head coil
  - Functional MRI: TR = 6s, TA = 2s, sparse sampling, FOV 192x192mm, voxel resolution = 3x3x3 mm^3, flip angle 90°.
  - Structural MRI: TR = 2530ms, TE = {1.64, 3.44, 5.24, 7.04ms}, flip angle = 7.0°, TI = 1400ms, voxel resolution = 1.0mm^3, FOV = 220×220mm.
- **Analysis**
  - Cortical reconstruction and parcellation: Freesurfer v5.3.0
  - fMRI data were analyzed with FSL v5.0.9, using Nipype v0.10.0 workflows implemented via openfMRI pipelines. FWHM = 6mm.
  - Functional connectivity data were analyzed with CONN v16b.
  - Voxel-level cluster-forming threshold $p < 0.05$ (two-sided); FWE-corrected cluster-level threshold $p < 0.05$.

PARTICIPANTS

- 29 typically developing children (5.8 – 9.8 years old), 30 typically developing adolescents (9.8 – 17.9 years old), and 23 healthy adults (18-34 years old) participated in the study.
- 4 children, 1 adolescent and 1 adult were removed from the fMRI analysis due to excessive motion (> 33 % of trials with greater than 3 mm motion).
- The remaining groups were not significantly different on gender ratio (p = 0.51) or standard non-verbal IQ (p = 0.26).

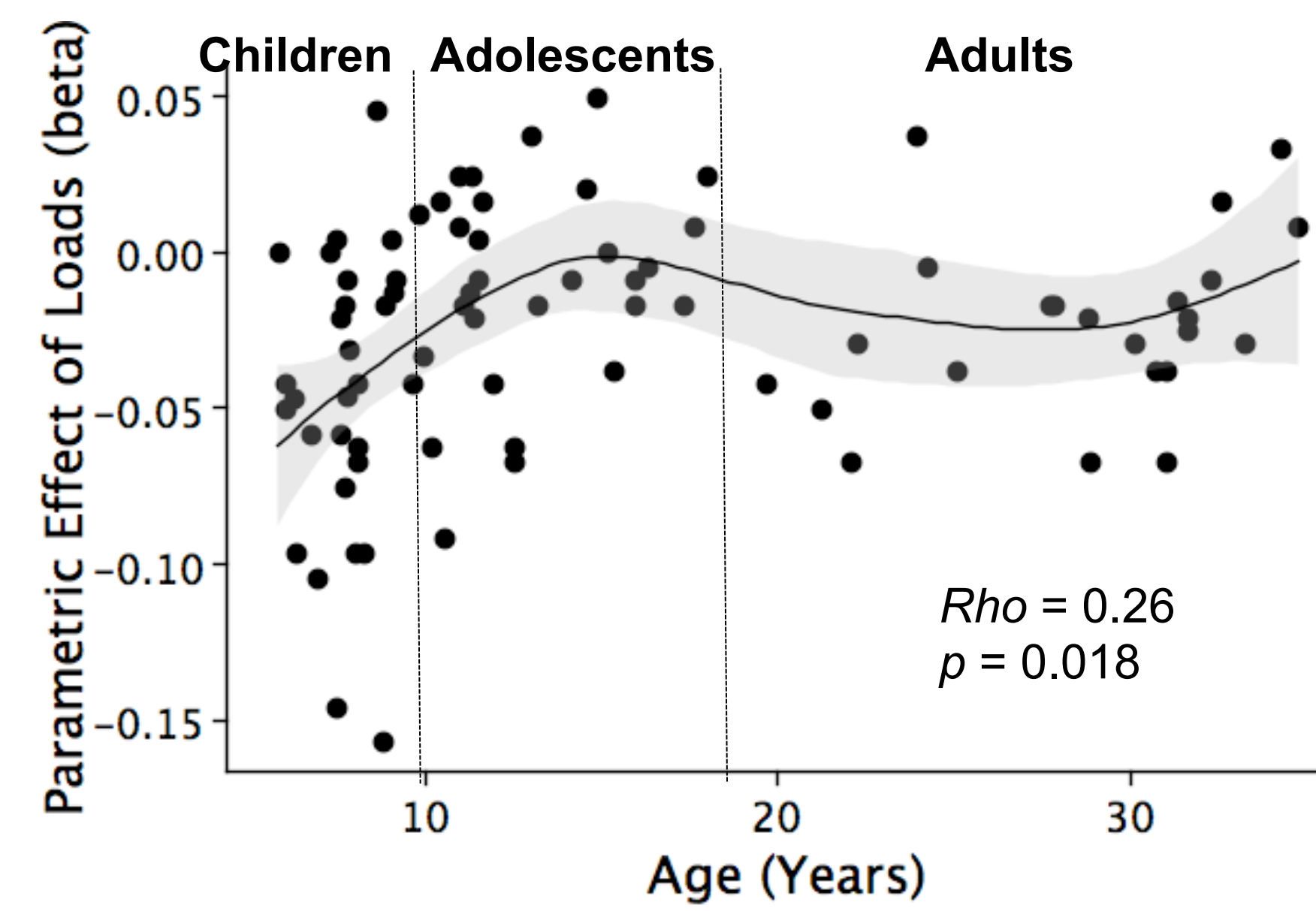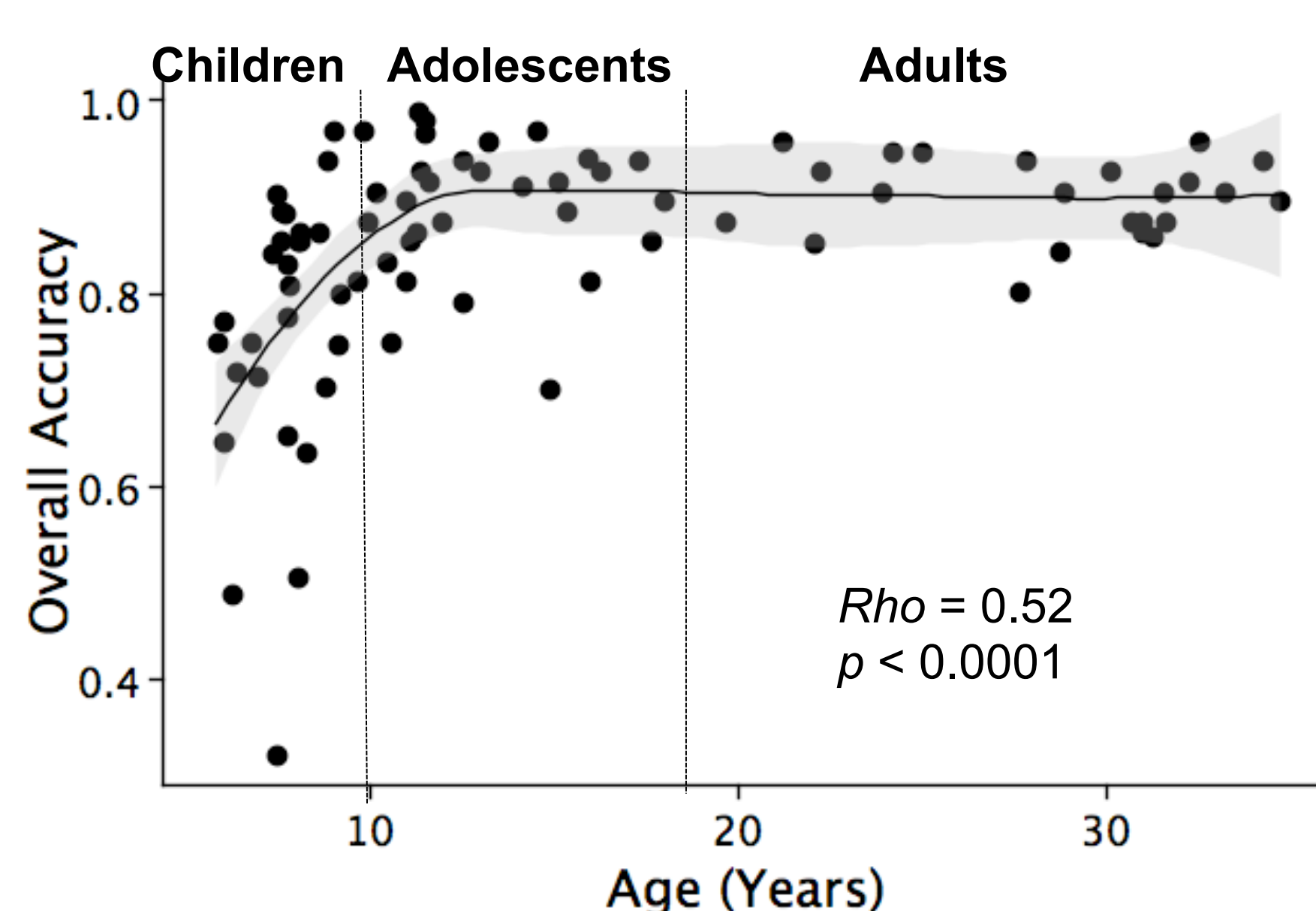| Group	Age	Gender (M:F)	Nonverbal IQ
Children (n=25)	7.7 (1.07)	16:9	115.9 (18.94)
Adolescents (n=29)	13.1 (2.57)	14:15	114.3 (11.81)
Adults (n=22)	28.4 (4.52)	12:10	120.7 (9.80)

BEHAVIORAL RESULTS
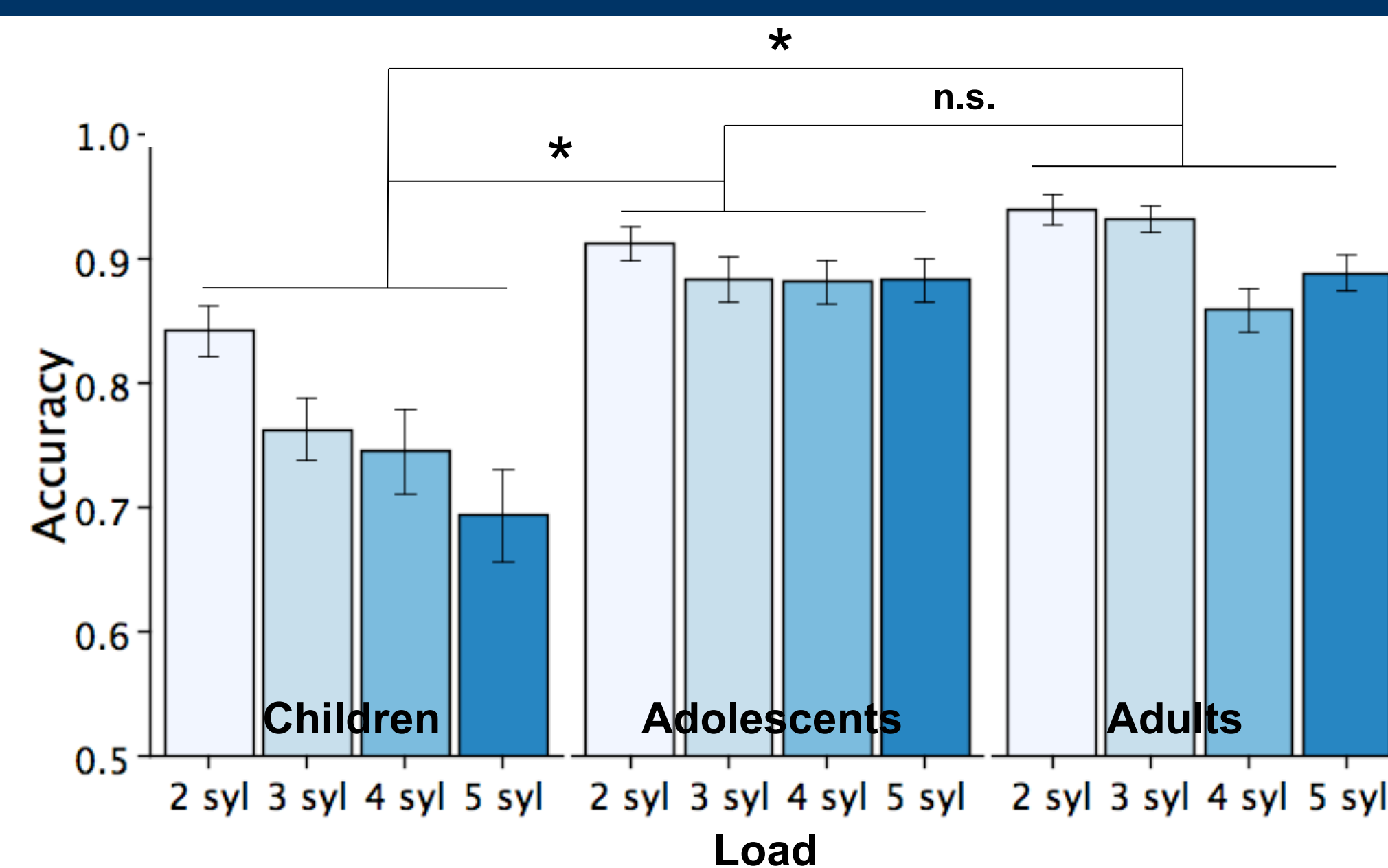
Repeated measures ANOVA:
Group: $F_{(2,79)} = 19.93$, $p = 9.80 \times 10^{-8}$
Load: $F_{(3,237)} = 16.64$, [1]$p = 3.75 \times 10^{-10}$
Condition x Load: $F_{(6,237)} = 4.15$, [1]$p = 8.73 \times 10^{-4}$
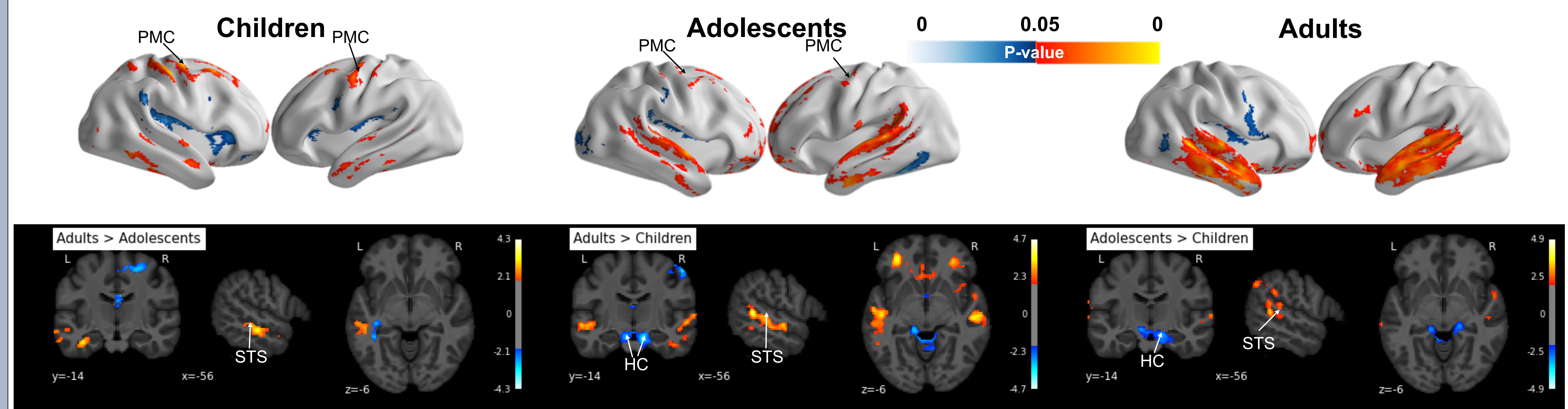
[1] p's corrected for violations of sphericity.

Children < Adolescents, Children < Adults
Adolescents and Adults are not different
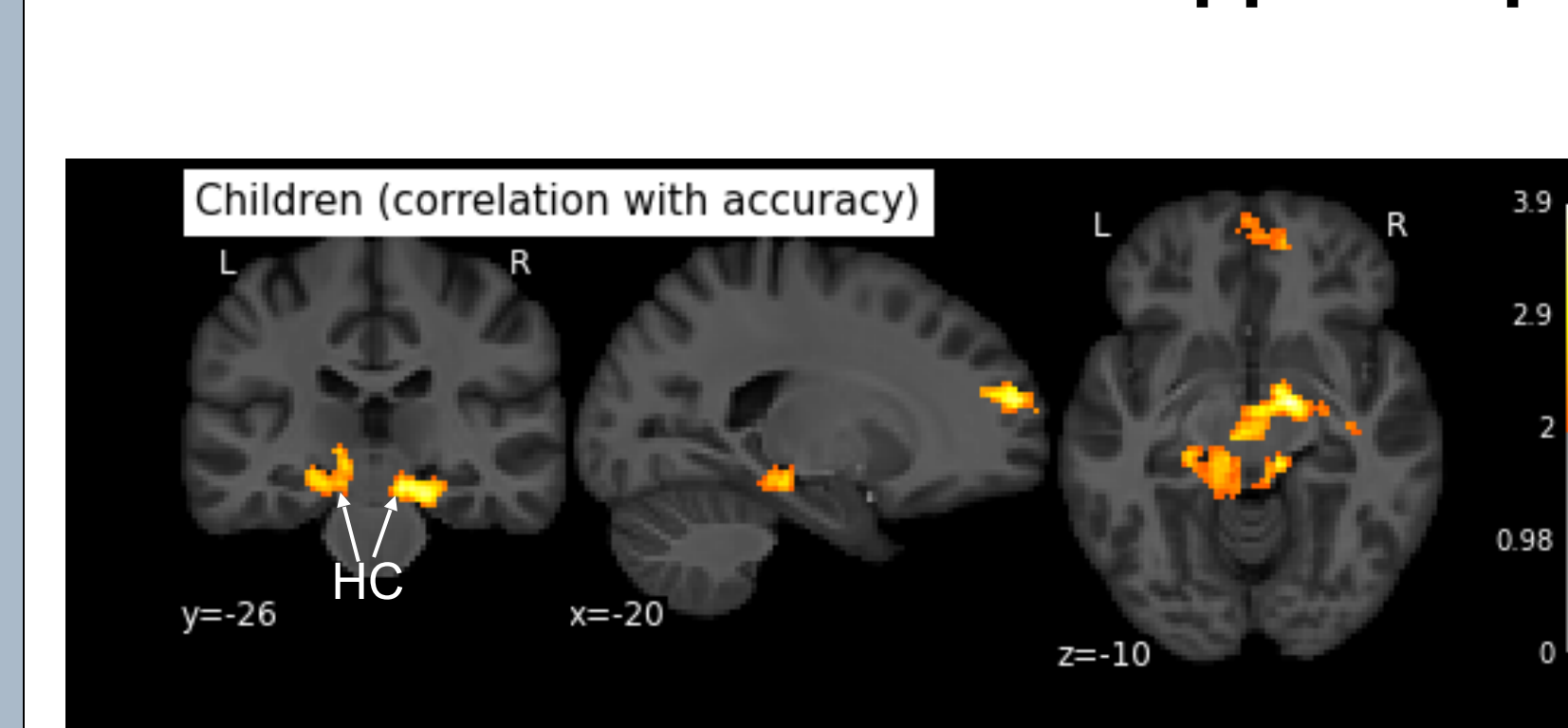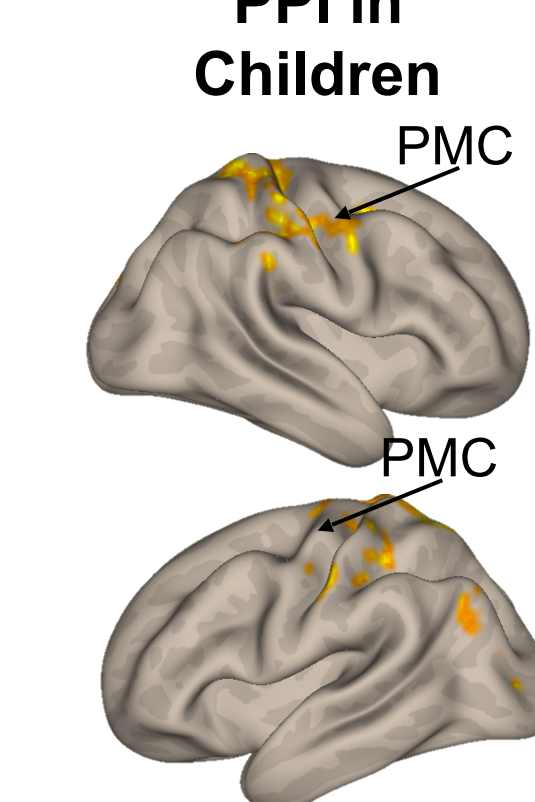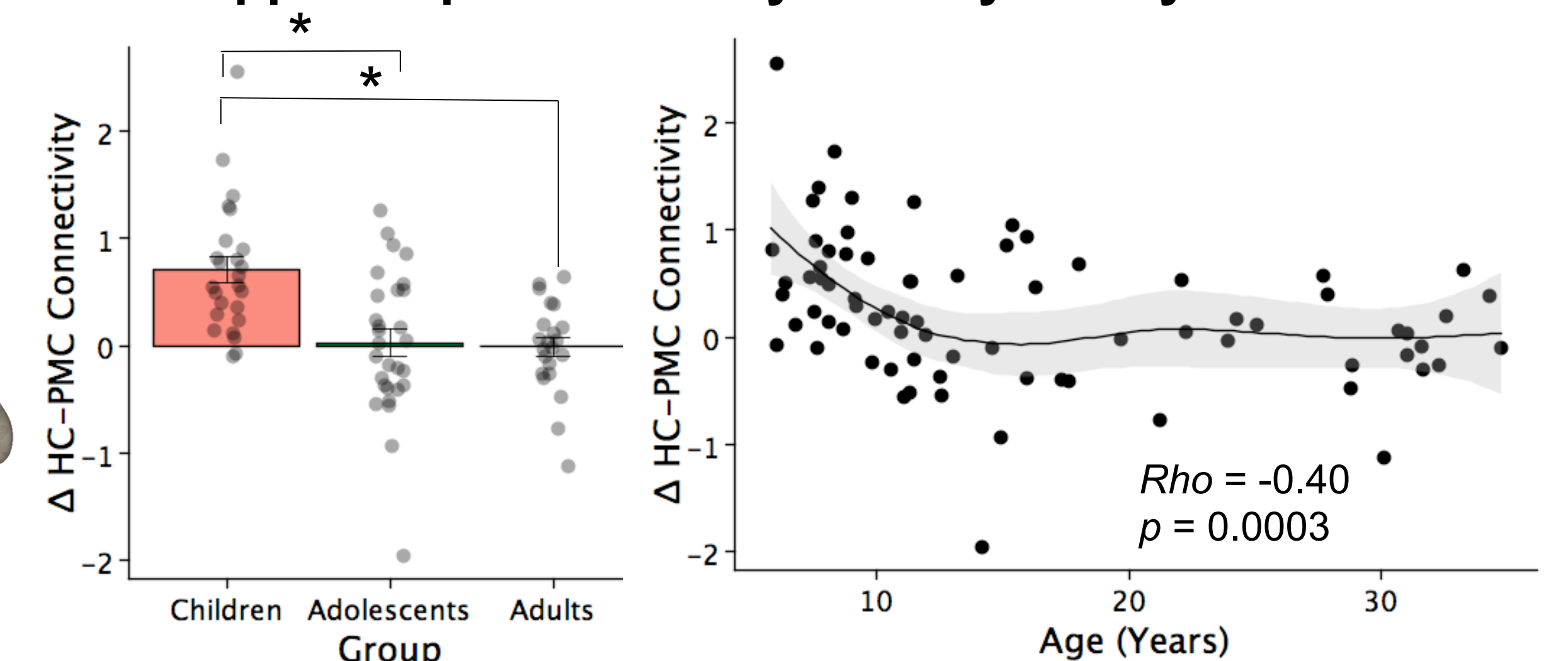* Bonferroni corrected $p = 0.0001$

Rho = 0.52
p < 0.0001

Rho = 0.26
p = 0.018

IMAGING RESULTS

Parametric Effect

Children · Adolescents · Adults
PMC · PMC · PMC · PMC
0 · 0.05 · 0
P-value

Adults > Adolescents · Adults > Children · Adolescents > Children

Correlation with Behavior: Hippocampus

Children (correlation with accuracy)

Hippocampus PPI Analysis: 5 syl > 2 syl

PPI in Children
PMC · PMC

Δ HC-PMC Connectivity
Children · Adolescents · Adults
Group

Rho = -0.40
p = 0.0003

Age (Years)

SUMMARY

- Parametric Effect
  - Increasing syllable length activates bilateral superior temporal gyri / sulci (STG/STS), premotor cortex (PMC), superior and inferior frontal gyri.
  - Adults / Adolescents > Children: Bilateral STS;
  - Adults / Adolescents < Children: Bilateral hippocampus (HC)
  - Adults > Adolescents: Left STS
- Role of Hippocampus
  - Only children's overall accuracy is positively correlated with the parametric effect in HC.
  - Children showed increased functional connectivity between HC and bilateral PMC (5-syl vs. 2-syl) than both Adolescents and Adults. Difference of HC-PMC connectivity between 5-syllable and 2-syllable conditions decrease significantly with age.

CONCLUSION

- Consistent to the development of visual working memory (Finn et al., 2010), brain areas dedicated to transient speech perception are increasingly involved in PWM, while the involvement of long-term memory system gradually attenuates.

- Long-term memory system might facilitate accurate repetition by offering critical support for retrieval of speech information.

ACKNOWLEDGMENT

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