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Introduction

- Phonological working memory (PHWM) problems are linked to ADHD pathophysiology and predict many learning outcomes (1, 2)
- ADHD is also associated with greater performance variability and longer response durations across cognitive tasks (3)
- Optimizing phonological WM in children with ADHD is a priority, and the factors impacting WM performance (accuracy/consistency) have significant educational/clinical implications
- Presentation modality influences performance in other important neurocognitive domains implicated in ADHD pathophysiology (4), but has not been examined for phonological WM.
- Most studies of phonological WM rely solely on auditory input, neglecting visual and the combination of presentations (i.e., simultaneous auditory + visual presentation)

Present Study

- The current study is the first to compare how different presentation modalities impact ADHD-related PHWM performance (accuracy/consistency) and response duration (duration/consistency) across different cognitive loads using 3 independent conditions:
 - Auditory presentation only
 - Visual presentation only
 - Dual presentation (i.e., simultaneous auditory + visual)

Method

Participants

- N=36 children with ADHD aged 8-13 years
- Children (13 female, 13 male) with diagnosis of ADHD based on:
 - Independent diagnostic using K-SADS semi-structures interview with parent
 - Parent and teacher ratings ≥ 1.5 SDs on BASC-2 Attention Problems and/or Hyperactivity Scales OR
 - Exceeding parent / teacher criterion score on Child Symptom Inventory-IV
- All ADHD Presentations (14 Combined, 8 Inattentive, & 3 Hyperactive / Impulsive)
 - Comorbidities: Oppositional (14%), Depressive (17%), Anxiety (14%), & Adjustment Disorders (3%)
- Exclusion: Neurological impairment, seizures, psychosis, or WASI VCI IQ < 85 (Table 1)

Primary Measures

- Three parallel forms of a phonological WM task similar to the WISC-IV Letter-Number Sequencing. All tasks were counterbalanced. Stimuli presented at 1 s intervals. All conditions were identical except presentation modality.
 - (1) **Auditory Presentation:** Stimuli presented audibly using pre-recorded stimuli
 - (2) **Visual Presentation:** Stimuli presented as alpha-numeric numbers in center of screen
 - (3) **Dual Presentation:** Stimuli presented from Auditory and Visual encoding conditions simultaneously
- Conditions also administered at four set sizes (3,4,5,6). Each set size included 12 trials presented in ascending order.
- Tasks administered at total 4 set sizes (3, 4, 5, 6) for a total of 48 trials.

Analyses

- Repeated-measures ANOVAs with LSD-post hocs
- Tier I** Overall Presentation Effects
- Tier II** Cognitive Load Effects

Dependent Variables

- Phonological working memory performance
 - (a) **Accuracy:** Number of stimuli correctly recalled per trial
 - (b) **Accuracy Consistency:** Standard deviation of Accuracy
 - (c) **Response Duration:** Mean reaction time of response across trials
 - (d) **Response Duration Consistency:** Standard Deviation of Response Duration

Table 1. Sample Demographics

Variable	M (SD)
Age	10.46 (1.36)
WASI-2 FSIQ	109.69 (14.38)
Hollingshead SES	49.78 (10.91)
BASC-2 Parent	
Hyperactivity	71.03 (12.82)
Attention Problems	67.50 (7.48)
BASC-2 Teacher	
Hyperactivity	58.43 (12.19)
Attention Problems	61.23 (9.03)
ADHD Current Presentation	N (%)
Combined	14 (56)
Inattentive	8 (32)
Hyperactive/Impulsive	3 (12)
Gender	
Male	23 (64)
Female	13 (36)

Note. WASI-2 VCI IQ = Wechsler Abbreviated Scale of Intelligence-Second Edition; Verbal Comprehension Index; FSIQ = Full Scale Intelligence; SES = Socioeconomic Status; BASC-2 = Behavior Assessment System for Children-Second Edition

References
 1. Kover, L. J., Alderson, R. M., & Butler, K. L. (2012). Moderators of working memory deficits in children with attention-deficit/hyperactivity disorder (ADHD): A meta-analytic review. *Clinical psychology review, 27*, 666-671.
 2. Sarver, D. E., Rappaport, M. D., Kofler, M. J., et al. (2012). Attention problems, phonological short-term memory, and visuospatial short-term memory: Differential effects on near and long-term academic achievement. *Learning & Individual Differences, 22*(1), 8-23.
 3. Kofler, M. J., Rappaport, M. D., Sarver, D. E., Raloff, J. S., Orban, S. A., Friedman, L. M., & Kofler, E. G. (2013). Reaction time variability in ADHD: A meta-analytic review. *Journal of Abnormal Child Psychology, 41*, 955-961.
 4. Alderson, R. M., Rappaport, M. D., & Kofler, M. J. (2007). Attention-deficit/hyperactivity disorder and behavioral inhibition: A meta-analytic review of the stop-signal paradigm. *Journal of Abnormal Child Psychology, 35*(5), 745-758.

Results

Tier I: Presentation Modality Effects

- Accuracy/Accuracy Consistency (Figure 1):**
 - Better accuracy and more consistent performance during the Dual relative either single modality (Accuracy Cohen's $d = 0.20$ to 0.43). Accuracy was better during Visual presentation than Auditory presentation ($d = 0.26$).
 - More consistent accuracy during Dual and Visual presentation than Auditory presentation ($d = 0.52$ to 0.68). Dual and Visual did not differ ($p = .22$).
- Response Duration/ Response Duration Consistency (Figure 2):**
 - Responses durations were shorter during Dual and Visual Presentation than Auditory presentation ($d = 0.76$ to 0.82). Dual and Visual did not differ ($p = .70$).
 - Response durations were more consistent during Dual and Visual presentation than Auditory presentation ($d = 0.52$ to 0.53). Dual and Visual did not differ ($p = .82$).

Tier II: Cognitive load by Presentation Modality Effects (Figures 3-6)

- All set size by presentation modality interactions significant ($p < .001$) except Duration Consistency.
- Single Modality Contrasts:** Auditory vs. Visual presentation produced superior performance but longer response times at the lowest cognitive load, whereas at higher cognitive loads visual presentation was generally associated with improved and more consistent performance, more consistent response times, and lower overall response durations relative ($d = 0.36$ to 0.82).
- Dual vs. Single Modality Contrasts:** Dual presentation was associated with more consistent performance than at least either single modality at lower cognitive loads ($d = 0.46$ to 0.67). Accuracy and response durations were similar to the best single modality across set sizes.

Figure 1.

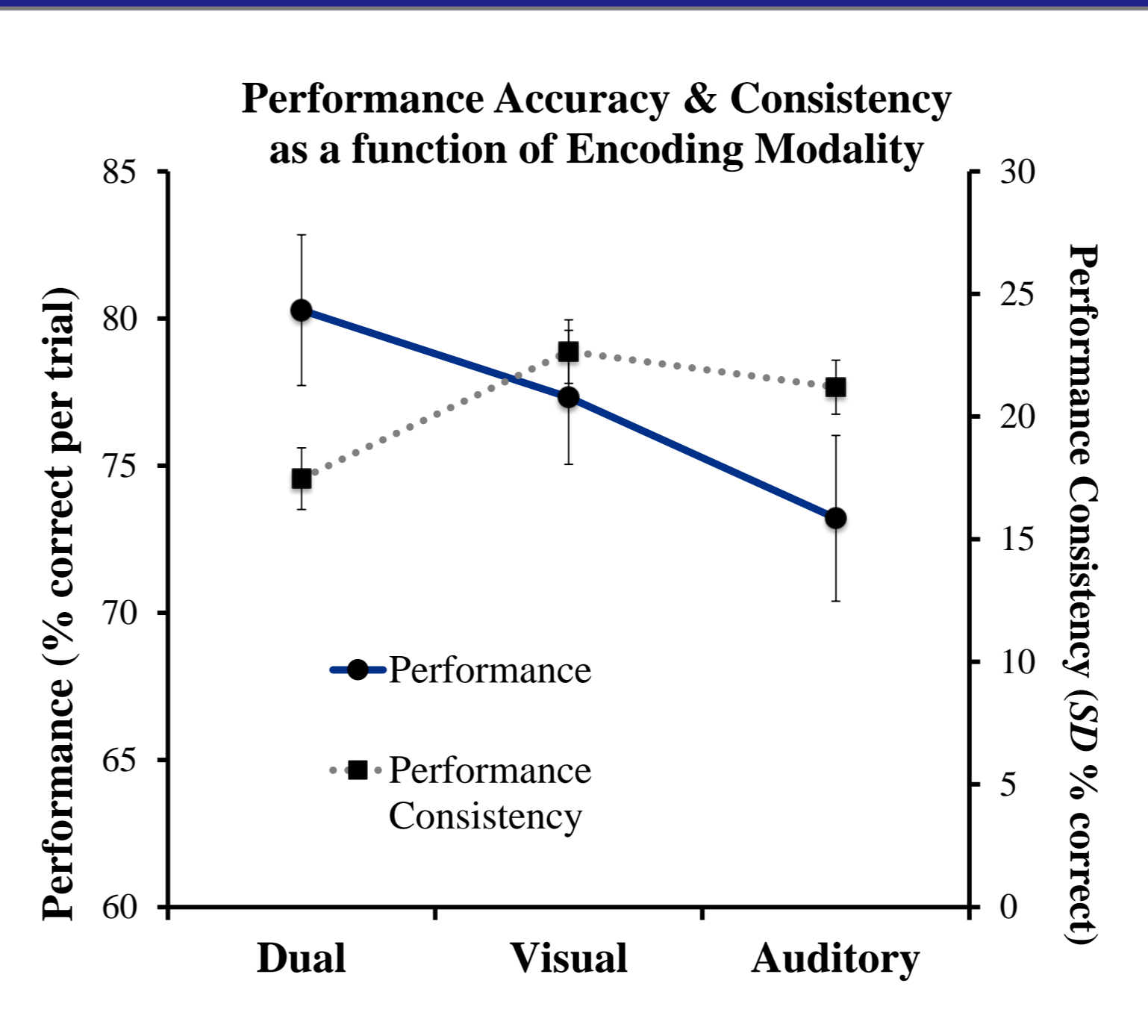


Figure 2.

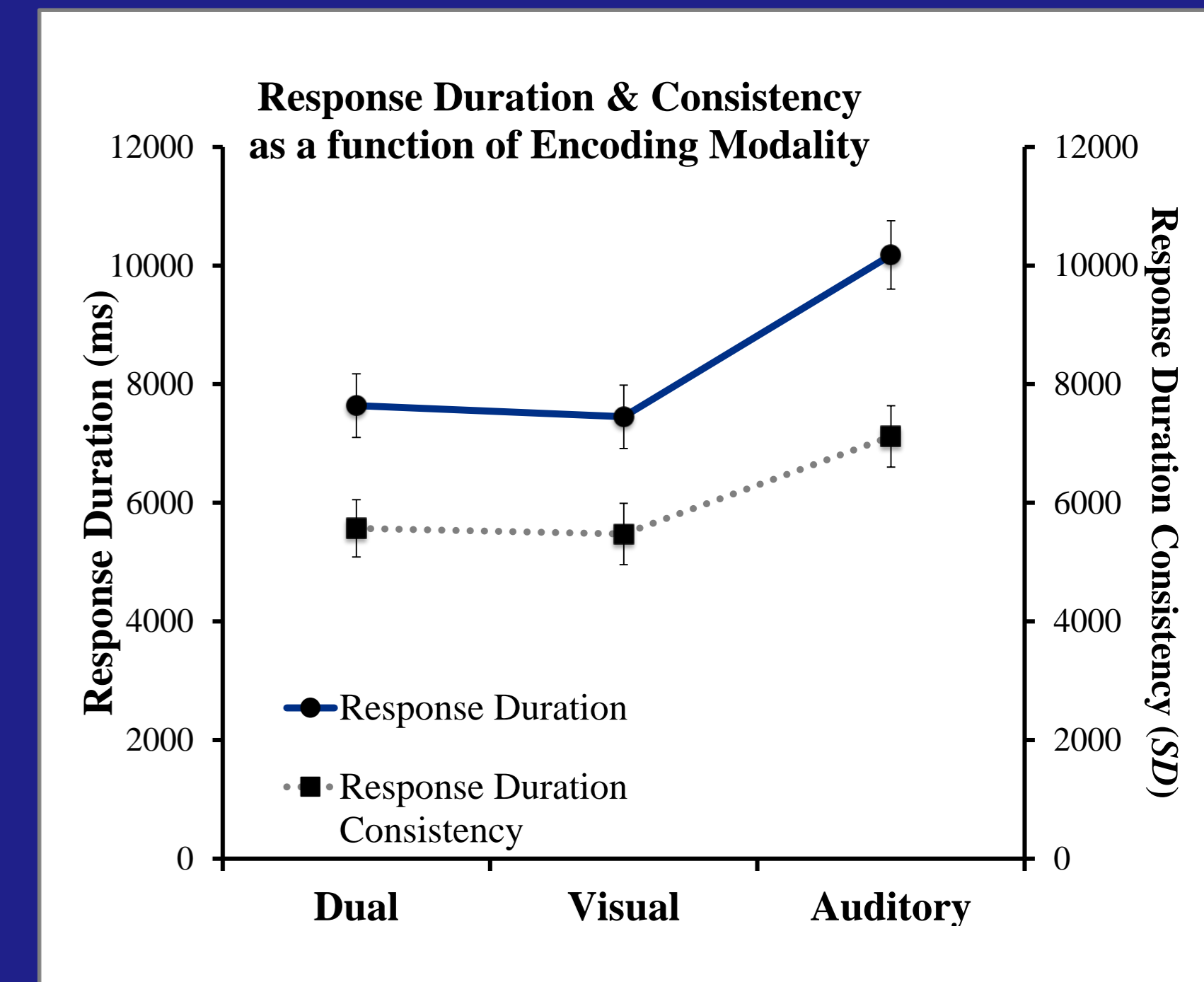


Figure 3.

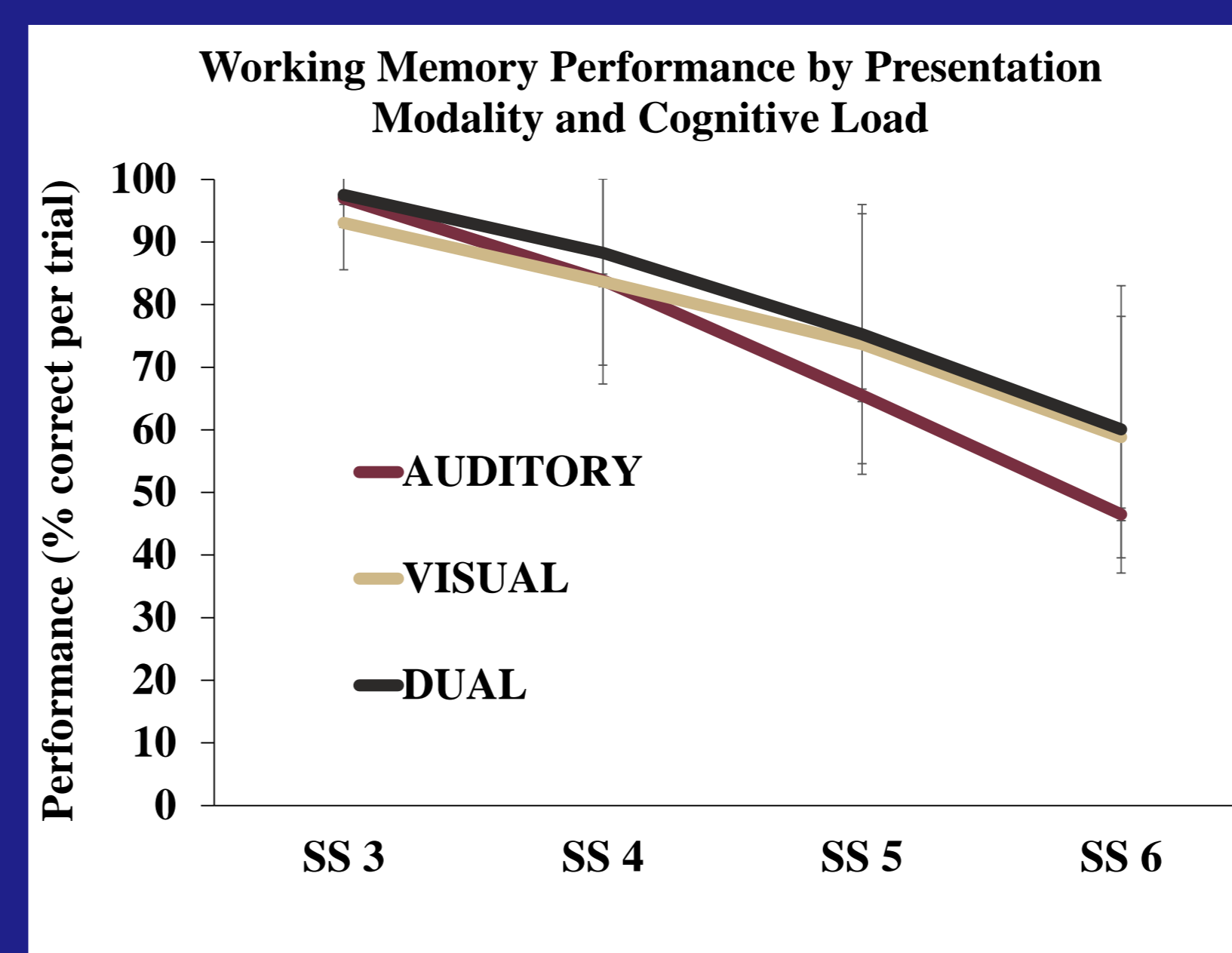


Figure 4.

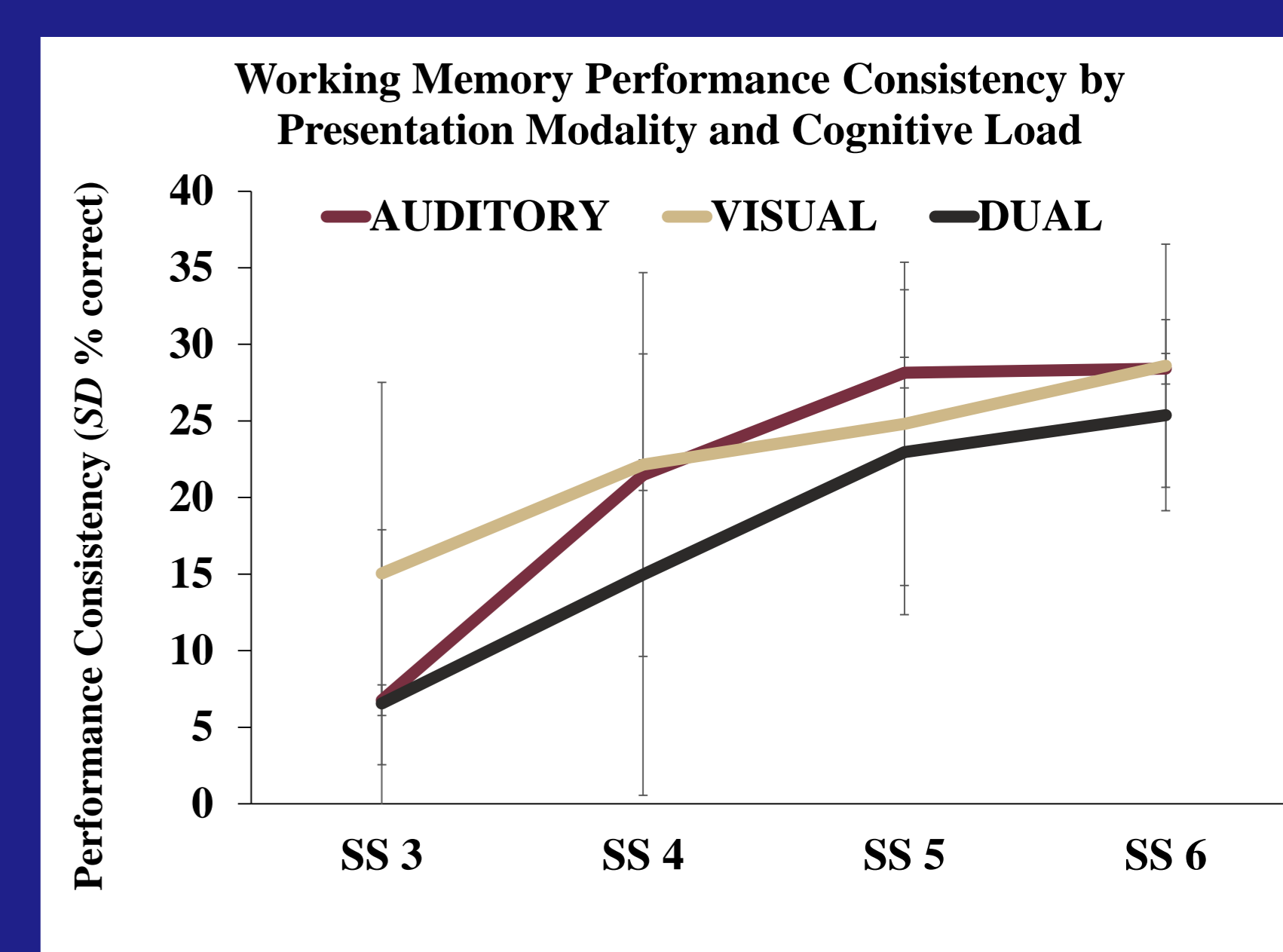


Figure 3.

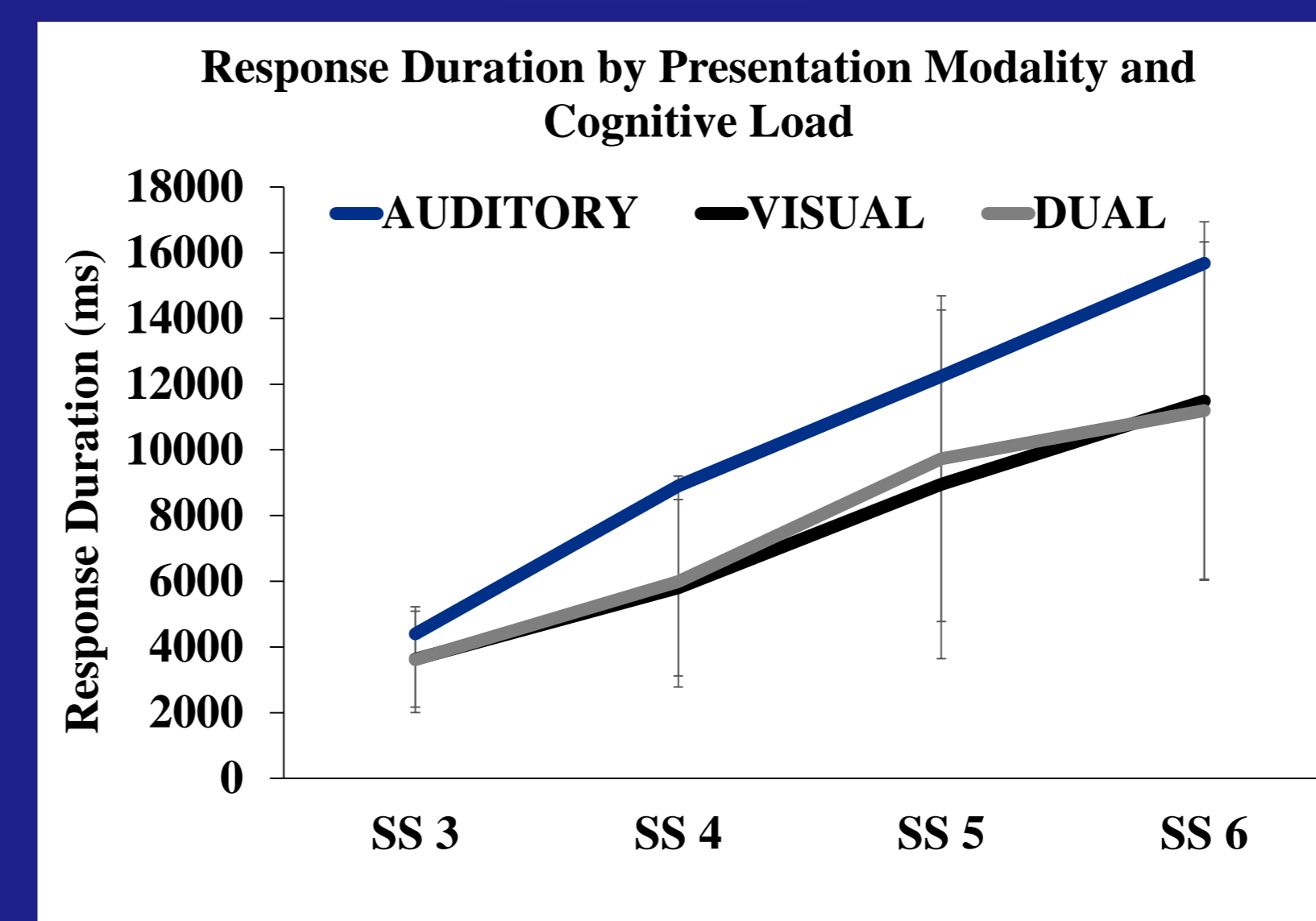
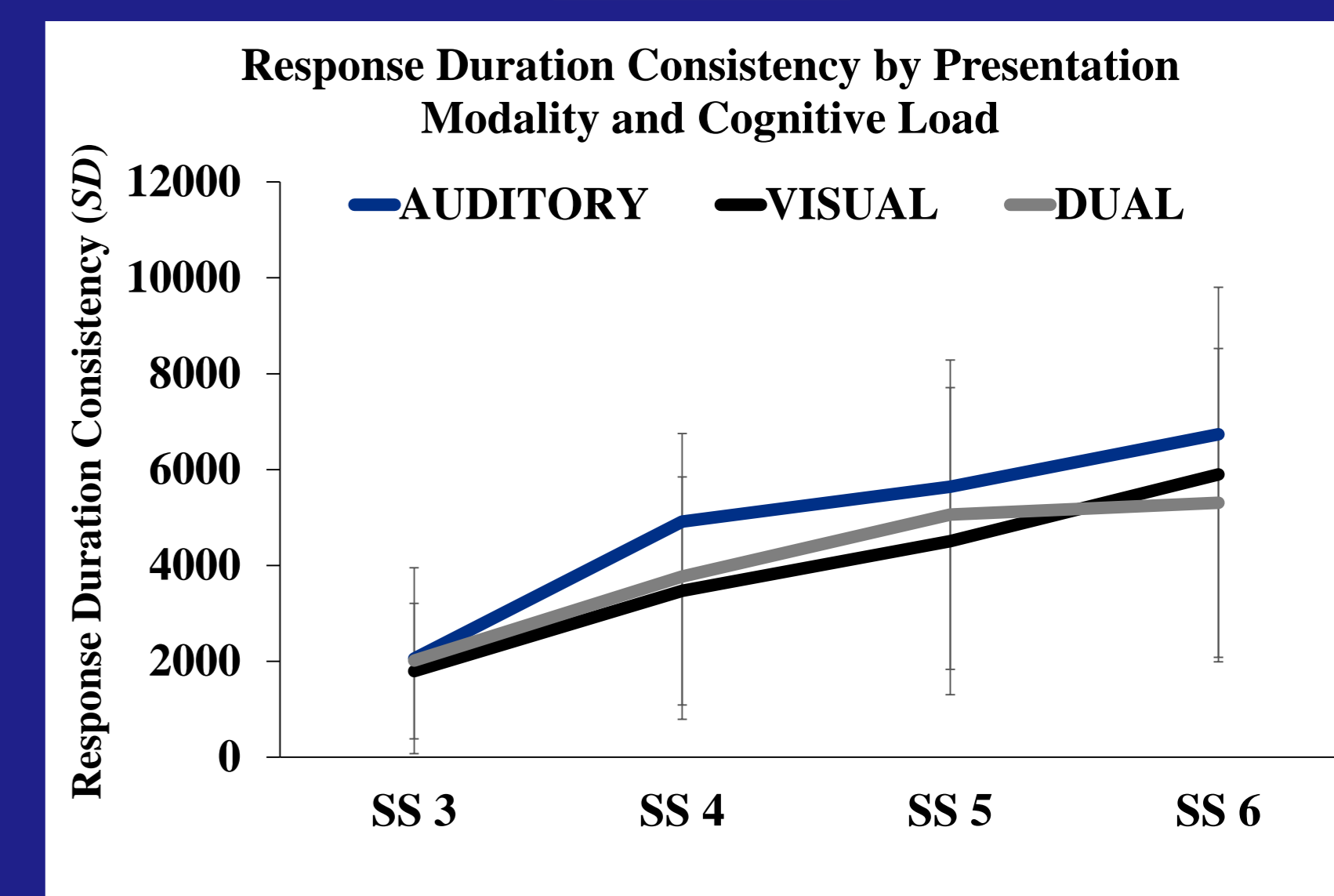


Figure 4.



Discussion

- Presentation modality impact phonological working memory performance in ADHD to a significant degree across indices.
- Auditory presentation associated with poorest WM performance and inconsistency, Dual presentation produces superior balance of phonological WM accuracy and consistency over single modalities,
- Has important implications for assessing phonological WM and improving classroom/academic and treatment outcomes.