Working Memory Capacity (WMC) and Listening Performance: Does method of WMC analysis affect its' predictive capabilities?

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ABSTRACT

During complex listening, executive functions such as working memory (WM) and attentional control (AC) are employed to separate target sounds from non-targets, or distractors. WM mechanisms are primarily responsible for holding targets, or features of targets, while inhibiting potential distractors. AC assists this process by maintaining and shifting focus between features of targets and away from distractors (Cowan, 2004; Dhamani, Leung, Carlile & Sharma, 2013; Hill & Miller, 2010). Should WM and AC not mediate distractors sufficiently, intrusions on task performance are observed. When exploring the relationship between these executive functions, research has shown inconsistent correlations between working memory capacity (WMC) and AC abilities. Specifically, some individuals with higher WMCs have shown more effective AC than individuals with lower WMCs when completing complex listening tasks (Guijo, Horiuti, Nardez & Cardoso, 2018; Luo, Zhang & Wang, 2017; Sörqvist, 2009); however, not all reports support this claim (Blasiman & Was, 2018). The current study examines whether this predictive capability is influenced by the method of WMC analysis. Normal hearing individuals between the ages of 18 and 30 had their WMCs measured via the Woodcock Johnson III Auditory Working Memory task. In addition, they participated in two subsequent listening tasks with reaction time (RT) and response accuracy as outcome measures. The participants' WMC scores (3-21) were analyzed via two methods: 1) continuum and 2) using a median split. We expect the continuum to be more predictive of listening performance, as it is more specific to individual WMCs and these differences may be averaged out using a median split. The results of this study will inform future research describing relationships between WM, AC, and complex listening.

INTRODUCTION

- Executive functions (EFs) (i.e., working memory (WM), attentional control (AC), inhibitory control, and cognitive fluidity) control intrinsic and extrinsic responses to stimuli, environments and tasks.
- Specific to complex listening, EFs work to reduce the negative effects of competing auditory signals and maintain task directives as well as targets for improved or optimal task performance.
- Although WM has been studied extensively with regards to complex listening, influence from WM is not readily agreed upon.
- WM, or the EF responsible for maintaining targets while excluding potential distractors is capacity limited. For the purpose of this study, working memory capacity (WMC) is defined as the ability to coordinate available resources during task engagement (Engle, 2002; Luo, Zhang & Wang, 2017).
- Studies investigating the correlation between WMC and task performance provide mixed results. For example, Kane et al (2001) suggested that individuals with higher WMCs were able to suppress distractors more effectively than individuals with lower WMCs; however, Beaman (2004) concluded individual differences in the ability to avoid negative effects of distractors were not a result of WMC.
- Discrepancies with experimental findings may result from the following factors: what function/process of WMC was being studied, how WMC was measured/defined, and performance of what cognitive function was WMC predicting (Blasiman & Was, 2018; Wilhelm, Hildebrand, & Oberauer, 2013).
- The current study investigated WMCs predictive capabilities over the selective attention (SA) subset of AC, as studies have shown WMC to be a good predictor of SA (Kane et al, 2001; Sörqvist, Nöstl & Halin, 2012; Sörqvist, Stenfelt & Rönnberg, 2012). SA was defined here as the mechanism responsible for distinguishing auditory inputs from each other (Hill & Miller, 2010).
- WMC was measured via the Woodcock Johnson-III Auditory Working Memory tasks, which was analyzed on both a continuum and following a median split procedure.
- The goal of this study was to determine whether the method of WMC analysis affects its' predictive capabilities across auditory SA tasks.
- We expected the continuum to be more predictive of listening performance across SA tasks as it is more specific to individual capacity limitations and excludes effects averaging across similar WMCs may cause.

METHODS

Participants:
7 native English-speaking adults ages 20-27 years gave their informed consent to participate in this study. All participants had normal hearing (i.e. thresholds ≤ 20 dB for .5, 1, 2 and 4 kHz) and normal or corrected to normal vision.

Working Memory Capacity (WMC):
The Woodcock Johnson-III: Auditory Working Memory complex span task was administered to measure individual WMC's. Scores were analyzed in two ways: 1) participants were assigned to the low group if they scored below 13 and to the high group if they scored 13 or higher and 2) scores were treated independently and evaluated on a continuum.

Stimuli:
Targets for each experiment were either a 1 kHz FM tone or a white noise burst that varied in duration (e.g., 100, 200, and 300 ms) based on experimental condition. Distractors were either a 1 kHz FM tone, white noise burst or sound that was not related to the target (e.g., animal noise). Participants were instructed to listen for the designated target in either their left or right ear.

Distractor Conditions:
3 potential conditions for competing sounds were present across all experiments:

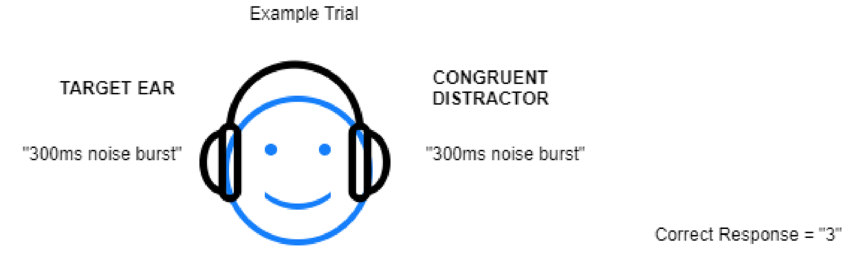
1) Congruent: distractors present were the same as the target
   - e.g. target = variation of white noise burst, distractor = same variation of white noise burst presented in the non-target ear
2) Incongruent: distractors present were a variation of the target sound not being used or a different variation of the target sound being used
   - e.g. target = variation of white noise burst, distractor = variation of 1 kHz FM tone; target = variation of white noise burst, distractor = different variation of white noise burst
3) Neutral: distractors presented were not related to the potential targets
   - e.g. target = variation of white noise burst, distractor = dog bark

Experimental Conditions

Ex1A: Dichotic Listening, Low Load

Participants were prompted to listen to a target sound presented in either their LEFT or RIGHT ear while disregarding competing sounds heard in the opposite ear. Targets were 200ms in duration and either a 1kHz FM tone (response = "1") or white noise burst (response = "3"). Competing sounds were equally likely to share a congruent, incongruent, or neutral relationship to the target.

Ex1B: Dichotic Listening, High Load

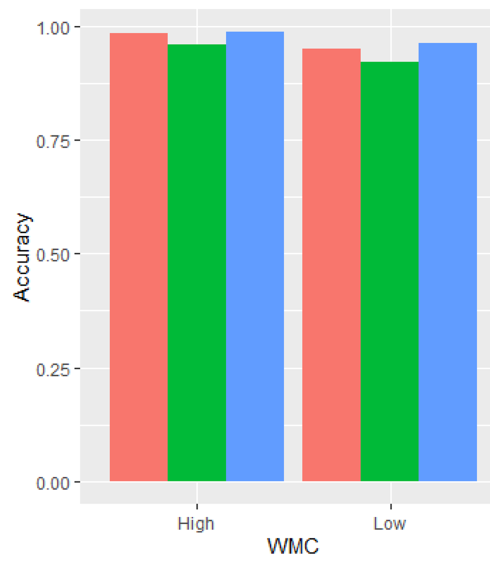


The procedure was the same as Ex1A; however, target sounds now varied in duration. Target pairs were either 100ms 1kHz FM tone/300 ms white noise burst or 300 ms 1kHz FM tone/100 ms white noise burst. A response of "1" corresponded to the tones, "3" to noise bursts, and "0" absence of a designated target (i.e., presentation of a 300ms tone when the target was a 100ms tone).

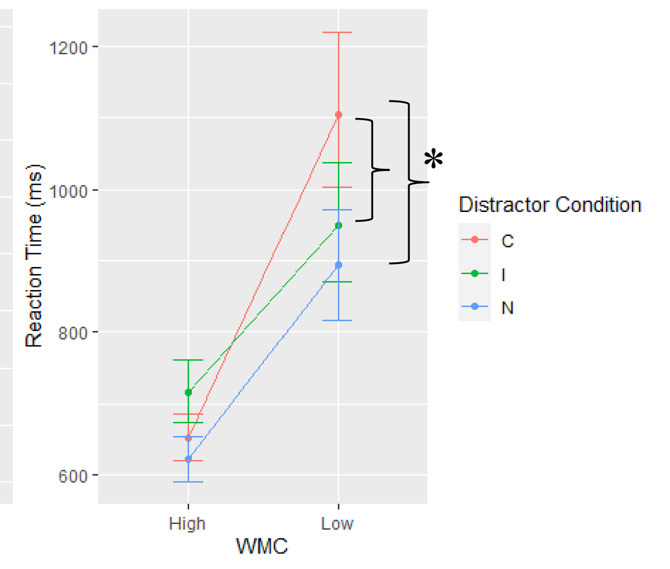
RESULTS

WMC Median Split Analysis

Ex1A: Accuracy



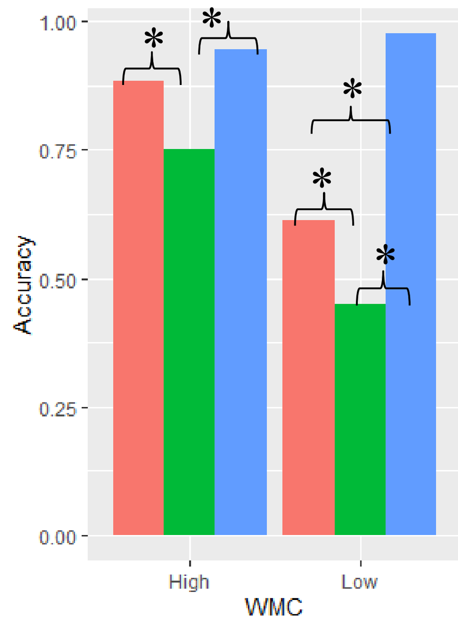
Ex1A: Reaction Time



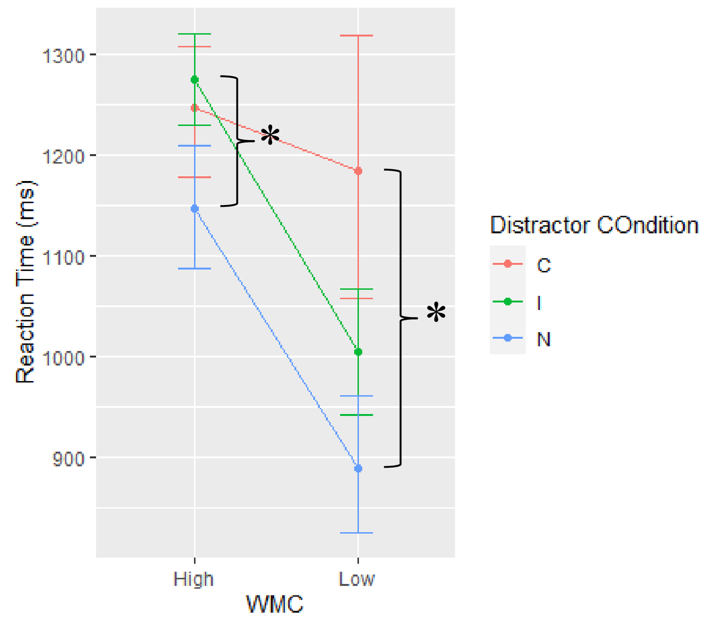
A mixed factorial ANOVA revealed main effects of WMC and distractor condition on reaction time (F(1, 1622) = 174.410, *p*<0.001; F(2, 1622) = 6.426, *p*<0.01) and accuracy (F(1, 1622) = 12.267, *p*<0.001; F(2, 1622) = 4.921, *p*<0.01). Post hoc analyses (Bonferroni adjusted) showed significantly slower reaction times for the low WMC group compared to the high WMC across all three distractor conditions (all *p*'s <0.001). Accuracy was also poorer for the low WMC compared to the high WMC group in the following conditions: low-incongruent to high-neutral (*p*<0.001) and low-congruent to high-neutral (*p*>0.01).

Significant differences in RT and ACC between distractor conditions within each WMC group are denoted with "*" on the above graphs.

Ex1B: Accuracy



Ex1B: Reaction Time

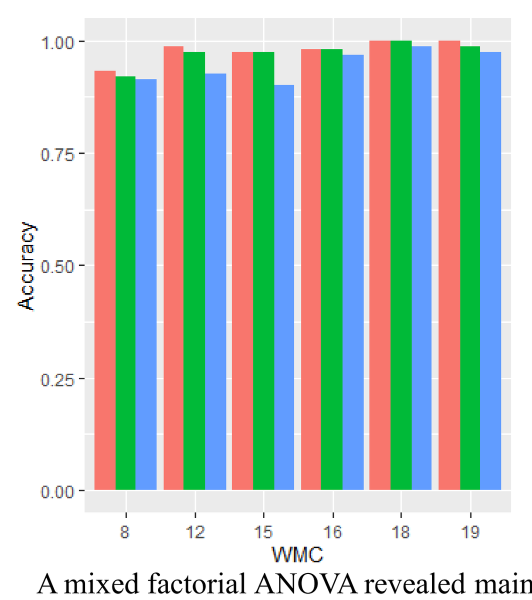


A mixed factorial ANOVA revealed significant main effects of WMC and distractor condition on RT (F(1, 1744) = 50.376, *p*<0.001; F(2, 1744)=9.569, *p*<0.001) and accuracy (F(1, 1744) = 102.94, *p*<0.001; F(2, 1744) = 83.22, *p*<0.001). Post hoc analyses (Bonferroni adjusted) showed longer RTs for the high WMC group compared to the low WMC group in the presence of **incongruent** distractors and **neutral** distractors, no differences were observed for the **congruent** distractor condition. Post hoc analyses also showed poorer accuracy for the low WMC group in both the **congruent** and **incongruent** distractor conditions. No differences in accuracy were observed for the **neutral** distractor condition.

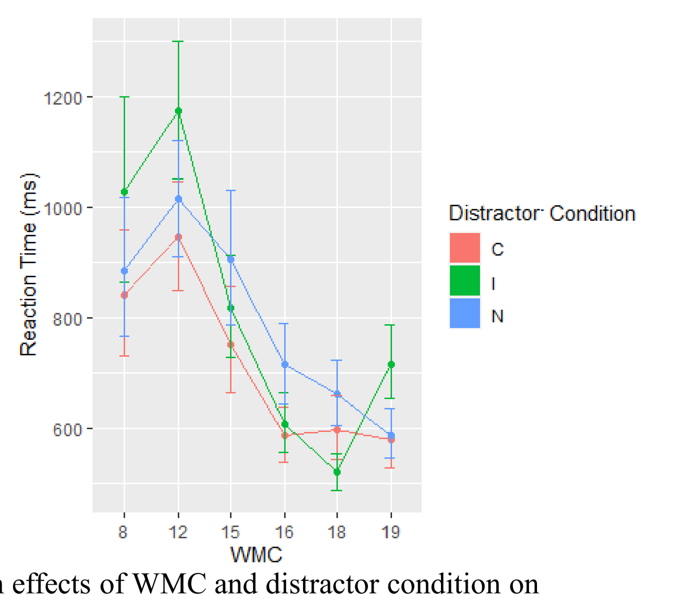
Significant differences in RT and ACC between distractor conditions within each WMC group are denoted with "*" on the above graphs.

WMC as a Continuum Analysis

Ex1A: Accuracy



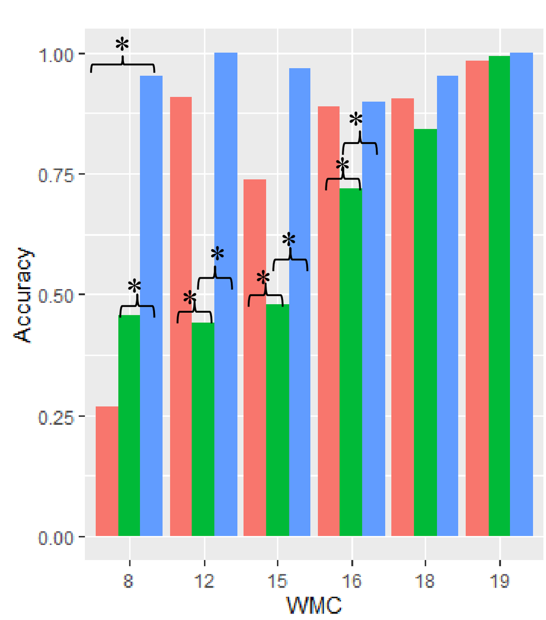
Ex1A: Reaction Time



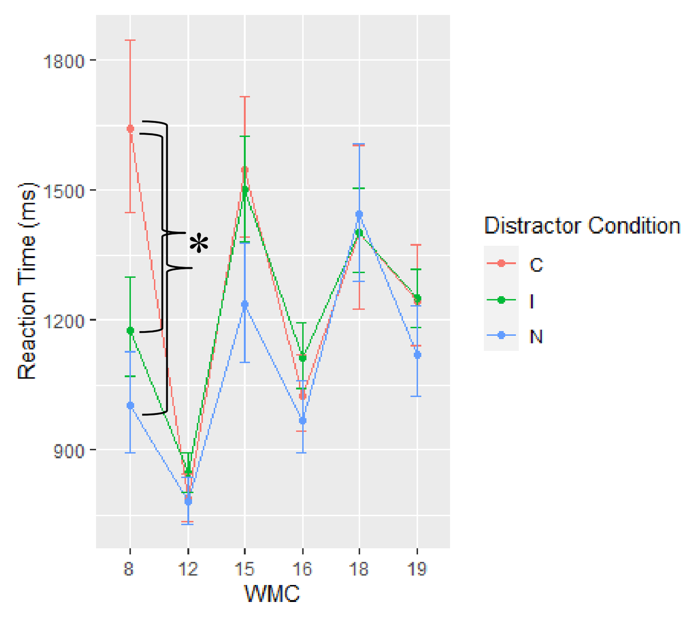
A mixed factorial ANOVA revealed main effects of WMC and distractor condition on reaction time (F(5, 1610)=46.56, *p*<0.001; F(2, 1610)=6.79, *p*<0.01) as well as accuracy (F(5, 1610)=5.559, *p*<0.001; F(2, 1610)=4.852, *p*<0.01). Post hoc analyses (Bonferroni adjusted) revealed slower reaction times in the presence of **incongruent** distractors for WMC scores of 8 than 19, 12 than 16, 18, and 19, and 15 than 19 (all *p's*<0.001), **congruent** distractors for WMC scores of 8 than 16, 18, and 19, 12 than 15, 16, 18, and 19, and 15 than 18 (all *p's*<0.01), and **neutral** distractors for WMC scores of 8 than 16 and 19, and 12 than 16, 18, and 19 (all *p*'s <0.01).

Reaction time performance did not differ across distractor conditions for any individual WMC measure.

Ex1B: Accuracy



Ex1B: Reaction Time



A mixed factorial ANOVA revealed significant main effects of both WMC and distractor condition on RT (F(5, 1732)=51.183, *p*<0.001; F(2, 1732) = 11.079, *p*<0.001) and accuracy (F(5, 1732)=50.18, *p*<0.001; F(2, 1732) = 94.91, *p* <0.001). Post hoc analyses (Bonferroni adjusted) showed significantly slower RTs during the **congruent** condition WMCs of 8 compared to 12, 16, and 19, WMCs of15 compared to 12 and 16, WMCs of 16 compared to 18, and WMCs of 18 and 19 compared to 12 (al *p*'s <0.001). Under the **incongruent** condition, RTs were slower for WMCs of 8 compared to 12 and 15, 15 compared to 12, 16 and 19, and scores of 16, 18 and 19 compared to 12 (all *p*'s <0.05). For the **neutral** distractor condition, RTs were slower for WMCs of 18 compared to 8, 12, and 16 and for 15 compared to 12 (all *p*'s <0.01). Post hoc analyses for accuracy revealed poorer performance for the **congruent** condition for those with WMCs of 8 compared to 12, 15, 16, 18, and 19 and for 15 compared to 19 (all *p*'s <0.05). Under the **incongruent** condition, performance was poorer for WMCs of 8, 12, and 15 compared to 16, 18 and 19, and for 16 compared to 19 (all *p's* <0.01). No accuracy differences were observed for the **neutral** condition.

Significant differences in RT and ACC between distractor conditions for individual WMC measures are denoted via "*" on the graphs provided above.

DISCUSSION

- The purpose of the current study was to investigate whether predictive capabilities of WMC on SA listening tasks change based on the method of WMC analysis (i.e., median split vs. scores on a continuum).
- Listening performance was evaluated across two dichotic SA tasks: 1) **Ex1A** assessed the listener's ability to identify a given target with simplistic perceptual features, in a directed ear, in the presence of competing stimuli, and 2) **Ex1B** assessed the listener's ability to identify the presence or absence of more complex targets based on finite perceptual cues (e.g., changes in duration). RTs and accuracy served as measures of performance for both tasks.
- When WMC was introduced to the data via median split, results for **Ex1A** showed significant increases in RT across all distractor conditions for the low WMC group; however, no between group differences were observed for accuracy. The method of evaluating WMC on a continuum again showed no differences in accuracy between WMC or distractor condition; however, a clear pattern of reduction in RTs as WMC increased emerged. For **Ex1A,** the method of analyzing contributions of WMC on a continuum informed how RTs may systematically change with increases or decreases in WMC. These findings support the hypothesis of better predictive capabilities when assessing WMC on a continuum.
- Results from **Ex1B,** when WMC was analyzed via median split, showed longer RTs for the high WMC group under the incongruent and neutral conditions, and poorer accuracy for the low WMC under congruent and incongruent conditions. Analyzing WMC on a continuum also showed poorer accuracy for those with lower WMC in the presence of incongruent distractors, yet did not reveal a consistent pattern of RT changes. Contrary to **Ex1A,** contributions of WMC were more informative for **Ex1B** using a median split method. These findings did not support the presented hypothesis.
- The limited number of subjects also could have influenced results. Specifically, significant RT differences were observed between WMC groups for **Ex1B,** yet there were no clear patterns when WMC was analyzed on a continuum; individual variability due to the small number may have resulted in this. Perhaps median split or group designs are more appropriate when the number of subjects for a study is low.
- Differences in predictive capabilities of WMC, depending on the method of WMC analysis, was observed between the two experiments. This finding is in line with disagreements presented by existing literature regarding whether WMC is a good predictor of performance (Beaman, 2004; Kane et al., 2001; Sörqvist, Nöstl & Halin, 2012).
- The present study does not propose that WMC is *always* predictive of listening performance; instead, results corroborate claims from researchers about the importance of providing clear definitions of, and explicitly stating the method of analysis used, when discussing potential contributions from cognitive measures (Blasiman & Was, 2018; Wilhelm, Hildebrand, & Oberauer, 2013).

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