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Working memory capacity affects the interference control of distractors at auditory gating

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ABSTRACT

It is important to understand the role of individual differences in working memory capacity (WMC). We investigated the relation between differences in WMC and N1 in event-related brain potentials as a measure of early selective attention for an auditory distractor in three-stimulus oddball tasks that required minimum memory. A high-WMC group (n = 13) showed a smaller N1 in response to a distractor and target than did a low-WMC group (n = 13) in the novel condition with high distraction. However, in the simple condition with low distraction, there was no difference in N1 between the groups. For all participants (n = 52), the correlation between the scores for WMC and N1 peak amplitude was strong for distractors in the novel condition, whereas there was no relation in the simple condition. These results suggest that WMC can predict the interference control for a salient distractor at auditory gating even during a selective attention task.

Key words: working memory capacity, auditory gating, interference control, inhibition, attention, event-related brain potentials (ERPs)

Introduction

Working memory involves dynamic interaction between memory maintenance and attention control in the service of complex cognition [2]. Working memory has limited capacity, and working memory capacity (WMC) is reportedly related to real-world cognitive tasks such as reading comprehension [6], following directions [7], and reasoning ability [8, 13]. WMC is thought to reflect domain-general executive attention in the central executive [5]. Recently, several studies have examined the relationship between attention and individual differences in WMC. WMC is required not only for high-level cognitive tasks, but also for low-level attention-type tasks. One approach to studying the central executive function is to examine the relation between individual differences in WMC and an attentional task. Several studies have reported that response inhibition was an important contributor to WMC [11, 12, 15], while another study had an opposite view on this relation [10]. A more recent study reported that response inhibition itself was not related to WMC [19].

Nigg proposed four kinds of inhibition: interference control, cognitive inhibition, behavioral inhibition, and oculomotor inhibition [17]. It has been suggested that behavioral inhibition (prepotent response inhibition) and interference control (resistance to distractor interference) could be combined into a single latent variable [10], but this is still unclear. A study with a dichotic listening task suggested that it was easier for a distractor (own name) to capture the participant's attention in a low-WMC group than in a high-WMC group [4]. In the high-WMC group, the distractor may have been filtered out at auditory gating. Therefore, WMC could be related to inhibition as interference control at sensory gating, rather than at the behavioral response. In a study using a memory task with a visual distractor, Minamoto et al. suggested that, in high-WMC participants, attention was inhibited at posterior perceptual areas by top-down modulation [16]. High-WMC participants may have superior interference control at sensory gating in the auditory and visual modalities. However, we can not exclude the possibility that their results reflect differences in attentional resources or general memory rather than attentional inhibition during a memory task. It is unclear whether WMC affects the inhibition of attention during a selective attention task that requires minimum memory. Attention control at sensory gating occurs earlier and requires less cognition than response inhibition. To distinguish attentional inhibition from response inhibition, the present study treated attentional inhibition at sensory areas as interference control.

WMC and attention are reportedly closely related, and this relation is important for controlled, sustained attention in the face of interference or distraction [8]. The relation between WMC and attention during a not typical memory task or attentional task is unclear. There may not be a relation between WMC and response inhibition [10, 19], and rather interference control could occur at auditory gating [4]. Event-related brain potentials (ERPs) are useful for examining early events, such as auditory gating. Several studies have used ERPs to examine distractor processing in human cognition, and many have examined selective attention in the auditory modality. The amplitude of N1 reflects early selective attention in the auditory cortex; this amplitude increases for task-relevant target stimuli and decreases for task-irrelevant stimuli (distractors) [1, 9]. Attention for a task-relevant stimulus was reportedly enhanced at auditory gating in high-WMC participants [3]. In that study, the amplitude of auditory N1 in a high-WMC group was larger than that in a low-WMC group, which suggested that attention control and the capacity to gate auditory information are strong modulators of higher cognitive function. Similarly, N1 amplitude has been reported to be associated with working memory [14]. However, no previous study has examined whether high-WMC participants could control attention toward a salient distractor stimulus at auditory gating. If high-WMC participants can maintain attention in the face of interference or distraction despite the use of a task that requires minimum memory, then an early ERP component, such as N1, in response to a distractor should be affected during an auditory attention task.

In the present study, we used ERPs to examine the relation between WMC and interference control at auditory gating. We did not use a dichotic listening task, as in the previous study, and instead used a three-stimulus oddball task because it is possible that the previous findings may have been due to differences in resources or general memory rather than gating per se at auditory gating. The gating in the three-stimulus oddball task is considered to be unaffected/less affected by general memory or the amount of resources because the present study did not involve a memory task or dual task, unlike the previous study. We designed two conditions that varied according to whether the distractor stimulus was simple or novel. The very novelty of distractor stimuli may itself be a distracting factor. Auditory N1 was enhanced in response to a novel sound compared to when the stimulus was not a novel sound [1, 9]. In this study, we used ERPs to examine whether processing for an auditory distractor differed according to WMC. If high-WMC participants in not a typical memory task can resist a distractor better than low-WMC participants, then the amplitude of N1, which reflects selective attention to auditory gating, should be small. We predicted that, while the processing of a simple distractor would not affect WMC, a salient novel distractor would affect WMC because of the superior interference control at auditory gating in high-WMC participants.

Materials and methods

Participants: Fifty-two students (ages 18-33, mean 23.1 (*SD*=3.2) years, 21 females) at Hokkaido University participated in the experiment. The WMC of each participant was assessed by the Japanese reading span test (RSPAN) [18]. Participants were assigned to a high- or low-WMC group in accordance with the criteria for an extreme-groups design [5]. Twenty-six of the total participants were classified within the upper (*n*=13) and lower (*n*=13) quartiles for the RSPAN score, and were considered the high- and low-WMC groups, respectively. All of the participants provided their written informed consent and reported normal hearing and normal or corrected-to-normal vision.

Procedure:

Reading span test (RSPAN). First, each participant performed the Japanese RSPAN [18]. Each sentence was printed on a single line across the center of a 13 x 18 cm white card. Each sentence contained a target word, which was located somewhere in the sentence and was underlined in red. Participants were asked to read each sentence aloud at their own pace and to memorize the target word. As soon as they finished reading a sentence, the next sentence was presented. After the participant had read all of the sentences in a set, they were asked to recall the target words of the set and to write them in a booklet in the order of presentation. The test started with two-sentence sets and proceeded to three-, four-, and five-sentence sets, with five trials for each set size. In addition, two practice trials of two-sentence sets were given at the beginning of the test. The RSPAN scores were calculated as the total number of complete words recalled.

ERP tasks. Participants performed two kinds of auditory three-stimulus oddball tasks (simple and novel). In the simple condition, standard (0.70 probability), target (0.15 probability), and simple distractor (0.15 probability) stimuli were presented binaurally through headphones in a random series. In the novel condition, standard, target, and novel distractor stimuli were presented in a similar manner. In both conditions, the standard stimulus was a 1000 Hz pure tone and the target stimulus was a 2000 Hz pure tone of 80dB SPL. Auditory distractor stimuli consisted of a pure 500 Hz tone in the simple condition and 48 environmental sounds in the novel condition, with an SPL of 80dB. There were 320 stimuli in each condition and the order of conditions was randomized across participants. The duration of each stimulus was 50 ms (50-ms plateau, 5-ms rise/fall), and the SOA was 1200 ms. Participants were instructed to respond as quickly and accurately as possible when the target stimulus was presented and to ignore when each distractor stimulus was presented.

Recording and data analysis: An electroencephalogram (EEG) was recorded from Fz, Cz, and Pz (according to the 10-20 system) with Ag/AgCl electrodes. Each electrode was referenced to an average of the two earlobes. A ground electrode was placed on the forehead. An electrooculogram (EOG) was recorded bipolarly from two electrodes located above and below the left eye. The EEG and EOG were amplified with a band pass of 0.05-30 Hz. Electrode impedances did not exceed 10 kΩ. The data were digitized at a rate of 250 Hz. ERP was computed for each participant by averaging the epoch from 100 ms before stimulus onset to 924 ms. Trials in which EEG or EOG exceeded 80 μV and trials with an incorrect response were excluded from ERP averaging. The N1 component was defined as the largest negative-deflection peak between 40 and 140 ms after stimulus onset at Cz. The data were analyzed using repeated-measures ANOVA.

Results

Behavioral data: The RSPAN score ranged from 5 to 66; mean 28.17 (SD = 12.6). Table 1 summarizes the characteristics of the high- and low-WMC groups. Table 2 shows reaction times and error rates in the ERP tasks for both groups. These behavioral data were separately subjected to a two-way ANOVA with factors of WMC (high and low) and condition (simple and novel). Reaction times with the novel condition were longer than those with the simple condition ($F(1, 24) = 19.5$, $p < .01$), but the main effect of WMC and the interaction between WMC and condition were not significant. Error rates for both groups were analyzed by two-way ANOVA (WMC x condition), but there were no significant findings.

Tables 1 & 2

ERP data: Figure 1 shows the grand-averaged waveforms for the high- and low-WMC groups in the simple and novel conditions up to 300 ms after stimulus onset. The N1 component was elicited as a negative-deflection peak at around 100 ms after stimulus onset. The N1 peak amplitude was larger at Cz than at Fz and Pz, and therefore we focused on N1 at Cz. The N1 peak amplitudes in the WMC groups were subjected to three-way ANOVA with factors of WMC (high and low), condition (simple and novel), and stimulus (target and distractor). The interaction between WMC, condition, and stimulus was significant ($F(1, 24) = 4.7$, $p < .05$). The results of simple interaction effects between WMC and condition were significant only for distractor stimuli ($F(1, 48) = 14.7$, $p < .001$). The effect of simple interaction between WMC and stimulus was significant only for the novel condition ($F(1, 48) = 11.0$, $p < .005$). The simple main effect of WMC showed that the peak amplitudes of N1 in response to target and distractor stimuli in the low-WMC group were larger than those in the high-WMC group in the novel condition (F(1, 96) = 6.4, $p < .05$; F(1, 96) = 35.2, $p < .001$, respectively).

Table 3 shows the mean N1 latencies for the high- and low-WMC groups. N1 latency for target and distractor stimuli was subjected to three-way ANOVA (WMC x condition x stimulus). The interaction between WMC and condition was significant (F(1, 24) = 6.2, $p < .05$). However, the simple main effect of WMC was not significant (F(1, 48) = 3.4, $p = .07$, in the novel condition; F(1, 48) = 0.3, $p = .60$, in the simple condition). The main effects of WMC, condition, and stimuli and other interactions were not significant.

Figure 1 & Table 3

Correlation analysis: We investigated the Pearson correlation coefficients between the RSPAN score and the N1 component for all 52 participants. The RSPAN score was positively correlated with distractor and target N1 peak amplitudes in the novel condition ($r = .53$, $p < .001$, $r = .36$, $p < .05$, respectively), but was only weakly correlated with distractor and target N1 peak amplitudes in the simple condition ($r = .15$, *ns*; $r = .20$, *ns*, respectively). Specifically, high-WMC participants showed a smaller N1 than those with low-WMC in the novel condition, but not in the simple condition. Figure 2 illustrates the relationships between the RSPAN score and N1 peak amplitude in both conditions. While the RSPAN score was negatively correlated with distractor and target N1 latencies in the novel condition ($r = -.28$, $p < .05$; $r = -.11$, *ns*, respectively), there were almost no correlations with distractor and target N1 latencies in the simple condition ($r = .06$, *ns;* $r = .11$, *ns*, respectively).

Figure 2

Discussion

The peak amplitude of an early negative component of the ERP differed as a function of the WMC as assessed by RSPAN. The peak amplitude of N1 for a distractor in low-WMC participants was larger than that in high-WMC participants. As expected, this effect was significant in the novel condition, but not in the simple condition. This result suggests that high-WMC participants, but not low-WMC participants, could resist the distractor in the condition for high distraction. As suggested in a previous study [4], the present results demonstrate that attention was controlled at auditory gating. Other studies have reported that individual differences in WMC did not affect response inhibition at the behavioral response [10, 19]. However, this study found that WMC affected interference control at auditory gating. Since we used a single task that required minimum memory, rather than a memory- or dual-task, this result suggests that WMC influences the ability to control gating at the stimuli-input stage, rather than general memory or the amount of resources.

The distractor N1 peak amplitude and the target N1 peak amplitude for the high-WMC group were both smaller than those for the low-WMC group. This suggests that high-WMC participants might be able to resist allocating attention even for a target stimulus at the early stage. This result was different from that in a previous study [3]. Even though target stimuli had the same parameters in both conditions, target N1 was only affected in the novel condition. Thus, the effect on target N1 might be due to the interference control of attention toward a distractor in the novel condition; i.e., high-WMC participants may perform the task with top-down modulation or goal maintenance that would help them to resist allocating their attention to all stimuli at auditory gating in the novel condition. In a previous study, interference control was not necessary because the task did not include a distractor [3]. Therefore, it appears that their study noted the enhancement of N1 in high-WMC participants. Based on the present results, WMC appears to be related to top-down modulation or goal maintenance that helps participants to control the allocation of attention in the novel condition. Similar results were reported by Minamoto et al. [16], who showed that the superior interference control in high-WMC participants depended on efficient top-down modulation from the left middle frontal gyrus to the posterior sensory areas. While their study involved a memory task with a visual distractor, their results were similar to those in the auditory attentional task in the present study. In addition, our findings are consistent with those of Redick et al. [19]. They proposed an association between WMC and the ability to maintain/retrieve under interference-rich conditions. Our study raises the possibility that this ability of the WMC in interference-rich conditions could function at auditory gating. Taken together, these results suggest that high-WMC participants can control their attention from top-down modulation to auditory gating.

We examined whether N1 latency was associated with the RSPAN score. N1 latency for the target stimulus was not associated with WMC in either the novel or simple conditions. In contrast, N1 latency for distractor stimuli tended to show a significant effect of group in the novel condition. In addition, a negative correlation was found between WMC and N1 latency for the novel distractor. Thus, the process of attention toward novel distractor stimuli in high-WMC participants was faster than that in low-WMC participants.

The relation between WMC and N1 in the present study could have an alternative interpretation. It is possible that the relation between WMC and the early filtering of distractor stimuli proceeds in the reverse direction; i.e., early filtering may predict WMC. To clarify this possibility, further research will be necessary.

Conclusion

Individuals with high- and low-WMC as assessed by scores on the RSPAN were tested in selective attention tasks that required minimum memory. The results indicated that individuals with high-WMC could control the allocation of attention for a distractor at auditory gating. This effect was most evident when participants were faced with a salient novel distractor. These findings suggest that WMC can affect interference control at the auditory gating stage even during a selective attention task.

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Figure captions

Figure 1. Grand-averaged event-related potential (ERP) elicited by the novel (upper panel) and simple (lower panel) conditions, averaged separately for the high- (black line) and low-WMC (gray line) groups. Waveforms are from the Cz electrode and show from 100 ms before stimulus onset to 300 ms.

Figure 2. Scattergrams of the peak amplitude of N1 and the reading span score for all participants (N = 52). The novel condition (target and novel distractor stimuli) is shown in the upper panel, and the simple condition (target and simple distractor stimuli) is shown in the lower panel. Asterisks indicate a significant correlation (**: p < .001; *: p< .05).

Highlight:

> Inhibitory role is important to understanding of working memory capacity (WMC).

> We studied the relation between WMC and interference control at sensory gating.

> Interference control of both novel and simple distractors was examined.

> Novel distractors elicited small N1 amplitude in subjects with high WMC than low WMC.

> WMC affects the interference control toward distractors at the sensory gating.

Table 1, Characteristics of the High and Low WMC Groups

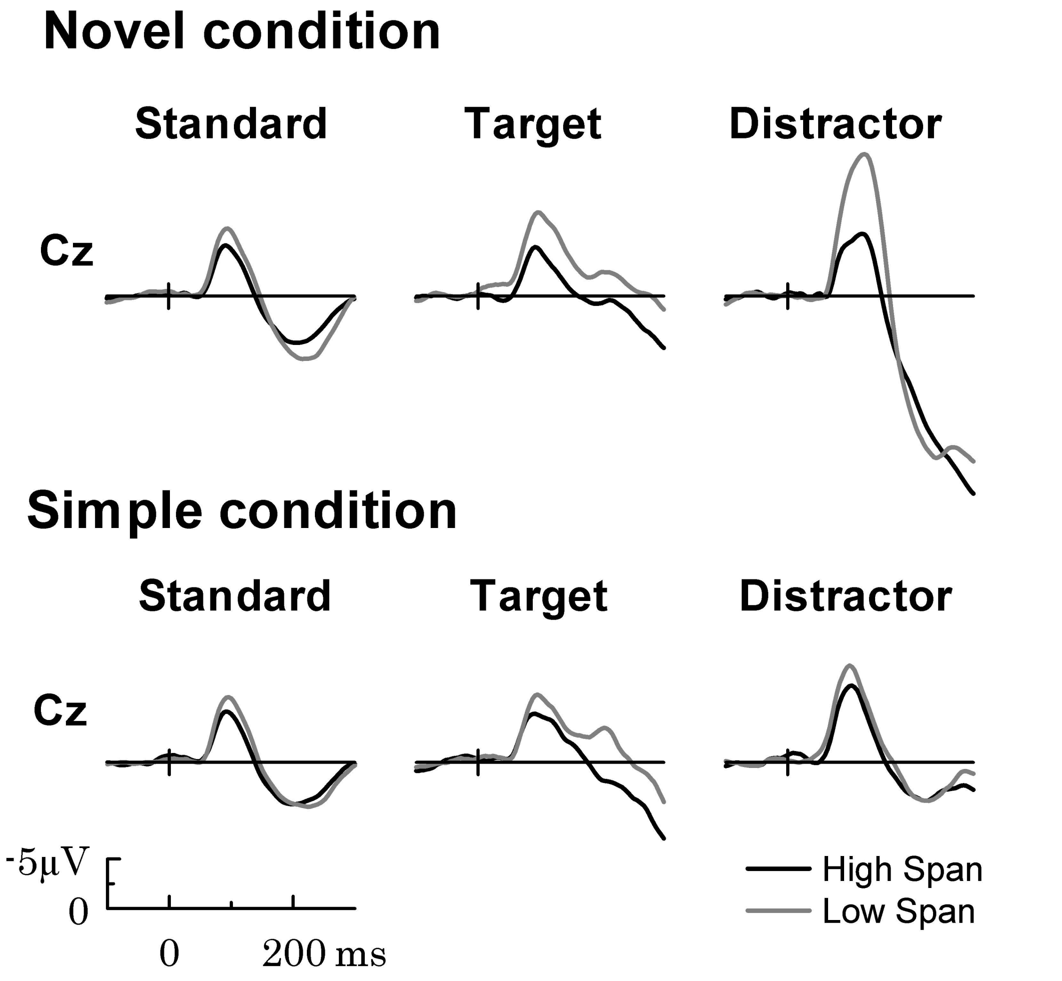
Group	Gender		Age		Reading span score	
	Female	Male	*M*	*SD*	*M*	*SD*
High WMC (*n* = 13)	4	9	24	3	44	8
Low WMC (*n* = 13)	6	7	23	4	13	4

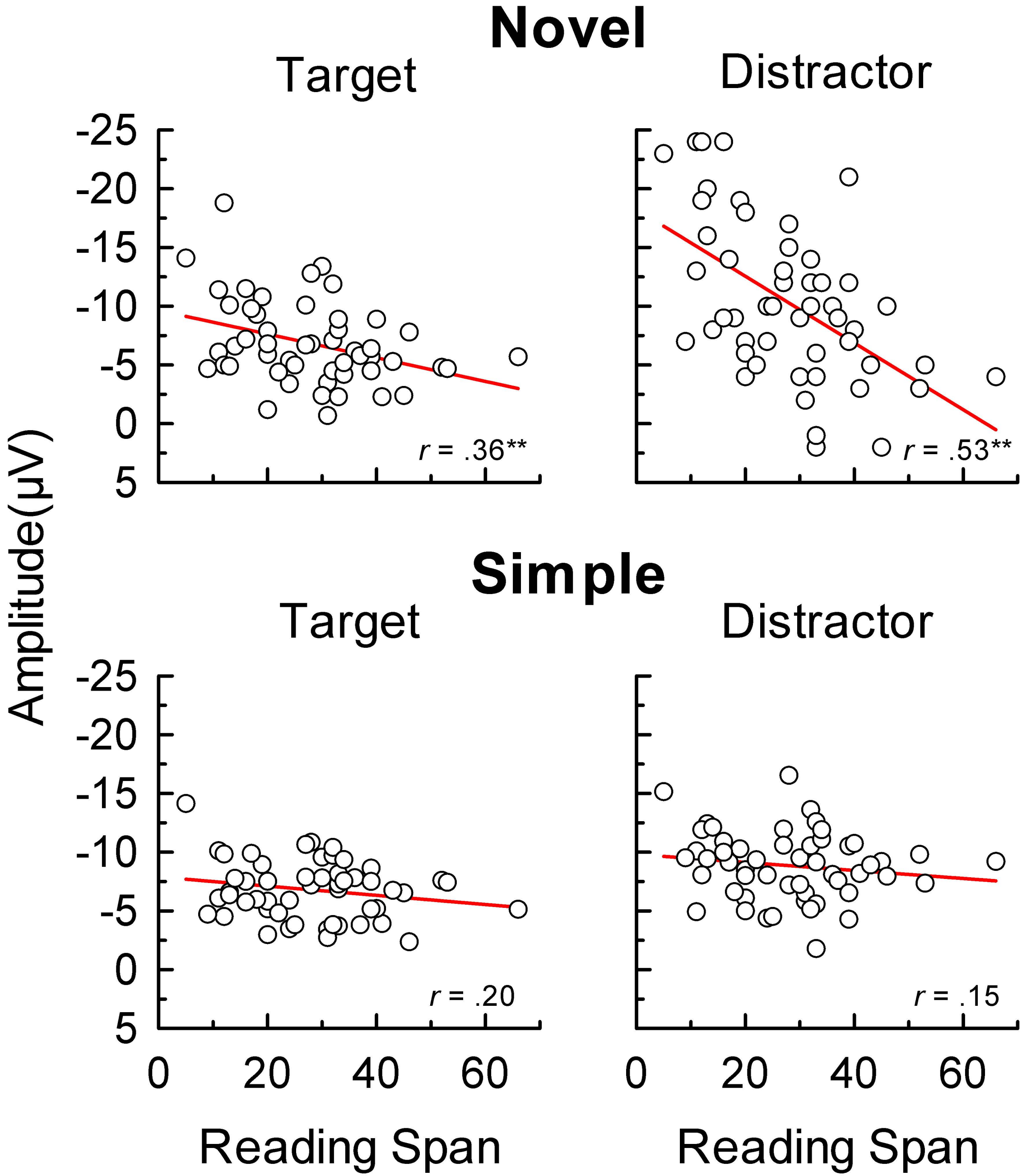
Table 2, Reaction Times (ms), Hit Rates (%), and the Number of Errors (*Mean* & *SD*) for Both Groups

		High WMC		Low WMC	
		M	*SD*	*M*	*SD*
Reaction time	Novel	386	60	396	52
	Simple	365	56	365	54
Hit rate	Novel	99.99	0	100.00	0
	Simple	100.00	0	100.00	0
# errors	Novel				
	Standard	0	0	0	0
	Non-target	0.01	0.01	0.09	0.27
	Simple				
	Standard	0	0	0	0
	Non-target	0.01	0.02	0.24	0.83

Table 3, Mean N1 Latencies (ms) for Both Groups

		High WMC		Low WMC	
		M	*SD*	*M*	*SD*
Novel	Target	98	17	106	15
	Non-target	103	22	113	18
Simple	Target	105	19	101	13
	Non-target	102	9	100	7


Novel condition
Standard
Target
Distractor
Cz
Simple condition
Standard
Target
Distractor
Cz
-5µV
0
0
200 ms
High Span
Low Span



Novel
Target
Distractor
-25
-20
-15
-10
-5
0
5
r = .36**
r = .53**
Amplitude(μV)
Simple
Target
Distractor
r = .20
r = .15
0
20
40
60
Reading Span
Reading Span