The implications of attention control on working memory span

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Abstract

Previous research has suggested that attention control is strongly implicated in working memory span. The current study utilized participants who had previously been tested for working memory capacity with the operation span, symmetry span and reading span tasks. Participants with high or low working memory spans where included in this study. These participants completed the Go/No-Go, Global/Local and Stop-Signal tasks, which examined different aspects of attention control. No significant differences were found between the working memory span groups on these three tasks.

The implications of attention control on working memory span.

Working memory has been described as the part of memory that is active and thus is seen as a system where both storage and processing of information occur (Oberauer, 2002). Existing research suggests that attention control is implicated in differences in working memory span (Redick & Engle, 2006; Ozonoff, Strayer, McMahon, & Filloux, 1994). The ability to control attention includes maintenance of the stimuli, goals and context of the information that is presented. This information must be easily accessed in the presence of distractions (Kane, Bleckley, Conway & Engle, 2001). It has also been suggested that the focus of attention determines what information goes into working memory (Lepine, Bernardin, & Barrouillet, 2005) and therefore directly affects the capacity of working memory (Oberauer, 2002). Berti and Schröger (2003) proposed that the function of working memory depends on the division of resources between a current task and possible distractions. Accordingly, in order to function optimally, the working memory system would need to control involuntary switching of attention.

Previous studies have found significant differences between individuals with high and low working memory spans in many different aspects. Bunting and Cowan (2005) found that low span participants had trouble maintaining the goal of a task when presented with distracting stimuli. In direct support that the idea that attention control is strongly implicated in working memory capacity, high span and low span participants did not differ on a task that did not require attention control (Conway & Engle, 1994) but did differ on a task that demanded large amounts of attention control but had little demand on memory capacity (Kane et al, 2001). Other studies have shown that individuals with high and low working memory spans differ on tasks involving visual attention control such as the Stroop task (Kane & Engle, 2003) and the Anti-saccade task (Unsworth, Schrock, & Engle, 2004).

The current study examined the differences between high and low working memory span individuals on three cognitive attention control tasks. These tasks were the Go/No-Go task, the Global/Local task and the Stop-Signal task. These tasks have individually been shown to identify differences in attention control. In the past, these tasks have been compared to some different working memory measures such as the Operation Span (Miyake, 2000), Reading Span (St Clair-Thompson, & Gathercole, 2006) and Digit Span (Finn, 2002). The current study aims to expand upon the findings that working memory span is associated with attention control by combining all three tasks and comparing performance between high and low working memory span individuals. Working memory span was determined in a previous study using the automated versions of operation span, symmetry span and reading span developed by Unsworth, Heitz, Schrock & Engle (2005).

The Go/No-Go task involves the presentation of two different stimuli. Only one of the stimuli is to be responded to. The stimulus that is being responded to is called the Go stimulus and the other stimulus is called the No-Go stimulus. This task requires the participant to withhold a response to one stimulus and establishes the response to the Go stimulus as a prepotent, or powerful, response. In the second half of the task, the two stimuli are switched so the previous Go stimulus is now the No-Go stimulus (Gomez, Ratcliff & Perea, 2007). This now requires the participant to withhold a prepotent response. Previous research shows that participants with poor attention control are more likely to continue responding to the first stimulus after they are instructed to switch. Poor performance on this task has been associated with autism and Tourette's syndrome (Ozonoff et al, 1994) and early-onset alcoholism and conduct disorders (Finn, Mazas, Justus & Steinmetz, 2002). We predicted that participants with low working memory spans would have more difficulties switching between the first and second blocks of the task. By this prediction we expected slower and less accurate responses from low span participants in the second part of the task.

The Local/Global task involves figures that are large (Global) letters made of smaller (local) letters. For half of the task participants are asked to identify the large figures. For the other half participants have to identify the small letters. Sometimes the global and local letters are the same (compatible) but sometimes they are different (incompatible). This task examines what people attend to when they are presented with an image and whether they process the image as a whole or by its features (Navon, 1977). Previous studies have shown that participants with low inhibition will have more trouble identifying the small figures than those with high inhibition (Ozonoff, 1994)). These results have been associated with academic achievement in children (St Clair-Thompson et al, 2006). Navon (1977) found that global figures are processed faster than local figures and that incompatible trials have the slowest reaction times (RTs). Based on this finding we predict that all participants will have slower RTs when identifying the local letters but low span participants will be slower than high spans, especially on incompatible trials.

In the Stop-Signal task participants respond to two stimuli (a circle and a square) but pressing a different button for each. Occasionally a tone occurs which indicates to the participant that they should not make a response. Logan (1994) describes inhibition as a race between a go process and a stop process. The go process is the response to the stimuli and the stop process is the inhibition of a response when the stop-signal occurs. If the go process "wins" the race then the participant will make a response. If the stop process "wins", then the participant will inhibit their response. This task measures a person's ability to inhibit a response that has already been initiated. Performance on this task has also been shown to correlate with academic achievement (St Clair-Thompson et al, 2006). Based on previous findings we expected to find lower accuracy and slower RTs from the low span participants.

Method

Participants

Participants (N = 41) were from the Atlanta area. They ranged in age from 18 to 34 years (mean = 24, SD = 4.18). Participants had previously participated in a study in which working memory span was measured. For the current study, participants with high and low working memory spans were included. Seventeen participants with low working memory span and 24 participants with high working memory span were included. Of the low span participants thirteen were female and four were male. Of the high span participants 20 were female and four were male. Compensation for participation was in the form of class credit or money.

Design

This study was a mixed design study. The main between subjects variable was working memory span group. Another between subjects factor, task order, was used in the Global/Local task. Within subjects factors included condition and trial type. The independent variables were span group, task order, condition and trial type. Dependent variable included accuracy and RTs for each task.

Materials

All of the tasks were programmed using E-prime and presented via a computer. Manual responses were used for all tasks and made through a response box.

Procedure

Tasks were presented in the same order to all participants. First was the Go/No-go task, then the Global/Local task and last the Stop-Signal task. We will explain the procedure of each of these tasks in the order in which they appeared to the participants.

The Go/No-Go task consisted of two blocks. In the first block participants were presented with letters one at a time. They were instructed to only respond if the letter was an X. An X appeared 80% of the time. In the second block participants were instructed to respond only if the letter was not an X. In this block an X was only presented 20% of the time. The main dependent variables for this task were accuracy of correctly not making a response to a non-X in the first block and to an X in the second block and reaction times.

The Global/Local task consisted of eight possible stimuli. These stimuli were large letters (global letters) made up of many smaller letters (local letters). Examples of these stimuli can be seen in *Figure 1*. The visual angle for the Global figures was 8.5 degrees by 5.1 degrees and the visual angle for the Local figures was 1.1 degrees by 0.4 degrees. These are similar to those used by Navon and Norman (1983). Participants were instructed to respond to either the global or the local letters. In one block participants responded to only global letters and in the other they responded to the local letters. The figures were defined as compatible, neutral, or incompatible. The only letters that occurred were H, S and X. Compatible figures occurred when the large letter was the same as the small letters that formed it, such as an H made of small H's. Incompatible figures occurred when the large letter and the smaller letters that make it up were not the same, such as an S made of small X's. When the global letters were being responded to, a neutral figure was an H or an S made of small X's. When the local letters were being responded to, a neutral figure was an X made of either small H's or S's. The dependent variables of concern in this task were accuracy and RT.

In the Global/Local task we counter-balanced the task order. Half of each of the span groups responded to the local letters in the first half block and the global letters in the second block. The other half of each of the span groups responded to the global letters in the first block and the local letters in the second block.

The Stop-Signal task had a square and a circle as the stimuli. Participants responded to each shape by pressing a different button. In 25% of trials a tone was additionally presented, which served as the stop-signal and indicated that the participant should not make a response. The stop-signal occurred at different intervals after the presentation of the stimuli; initially the tone occurred 250 ms after the stimulus. This interval is known as the Stop-Signal Delay (SSD). If the participant correctly stopped their response then the SSD would increase by 50ms. If the participant failed to stop their response then the SSD was decreased by 50ms. This change in delay between the stimulus and the stop-signal aimed to result in inhibition on 50% of Stop-Signal trials. Because of this fact, participants will be told that in some cases it would be impossible to inhibit a response and they should not slow their responses to try to wait for the tone.

Based on how often the participant is correctly able to inhibit a response, a stop-signal RT was calculated. This RT measure is the main dependent variable for this task. We also looked at accuracy of responses on trials with no stop-signal.

Results

One high span was excluded from all analyses because of extremely low accuracy on all tasks. In addition, on the Global/Local task, one low span was removed from the analyses because she reversed the response mappings for ‘H’ and ‘S’. Finally, on the Stop-Signal task, computer malfunction led to the loss of data from one low span and two high spans. One high span was removed from the Stop-Signal analyses because she reversed the response mappings for squares and circles, and one low span was removed because she was identified as an outlier based on her median correct RT on trials without a stop signal, indicating she was waiting to see if a stop signal was presented before responding. An alpha level of $p = .05$ was used for all of the following analyses.

Go/No-Go

For the Go/No-Go task we performed a mixed analysis of variance (ANOVA) with two within-subjects variables, Trial type (go or no-go), and Block (first or second), and one between-subjects variable, Group (high or low). There was a significant effect of trial type on accuracy, $F(1, 38) = 46.036$; $p < .005$. Participants were more accurate on Go trials than No-Go trials. Block also had a significant effect on accuracy, $F(1, 38) = 42.452$; $p < .005$. Participants made more errors on trials in the second block than in the first block. However, there was no trial type by group interaction, $F(1, 38) = .652$; $p = .424$, and there was no block by group interaction, $F(1, 38) = .019$; $p = .892$. There was a significant trial type by block interaction, $F(1, 38) = 35.001$; $p < .005$. While the span differences were in the direction that we expected they were not significant, $F(1, 38) = .689$; $p = .412$. Accuracy results can be seen in *Figure 2*.

We looked at RTs for correct responses to go stimuli and incorrect responses to no-go stimuli separately. There was a significant difference between correct RTs in the first and second blocks, $F(1, 38) = 53.33$; $p < .005$. However, there was not a significant difference for correct RTs between the two span groups, $F(1, 38) = .026$, $p = .872$, nor was there a block by group interaction, $F(1, 38) = 3.009$; $p = 0.091$. For responses that were incorrectly made to the no-go stimuli there was a significant difference in reaction times from block one to block two, $F(1, 38) = 8.981$; $p < .005$, but there was not a significant difference between the two span groups, $F(1, 38) = .055$, $p = .816$, and there was no block by group interaction, $F(1, 38) = .584$; $p = .451$. Participants were faster to respond to both go and no-go stimuli in the first block than in the second block. Contrary to our expectations, the marginal Block x Group interaction for go stimuli indicated that high span participants were disproportionately slower in block two after switching the response contingencies than low span participants. Reaction time results can be seen in *Figure 3.*

Global/Local

For the Global/Local task we performed a mixed ANOVA with two within-subjects variables, Condition (global or local), and Trial type (compatible, neutral, or incompatible), and two between-subjects variables, Task order (global first or local first), and Group (high or low). Because Task Order showed no significant main effects or interactions with either accuracy, $F(1, 35) = .334$; $p = .567$ or RT, $F(1, 35) = .001$; $p =$

.975, as the dependent variable, we collapsed across this factor for the analyses reported below.

Starting with the accuracy results, there was not a significant effect of condition, $F(1, 35) = .012$; $p = .915$. Trial type had a significant effect on accuracy, $F(1,35) = 17.142$; $p < .005$. Participants were more accurate on the compatible and neutral trials than on the incompatible trials. There was no significant main effect of span group, $F(1, 35) = .543$; $p = .466$, and there was no significant interaction between condition and span group, $F(1, 35) = .457$; $p = .503$. There was no interaction between condition and trial type, $F(1, 35) = 1.321$; $p = .274$. or between trial type and group for accuracy, $F(1, 35) = .633$; $p = .534$. There was also no 3-way interaction between condition, trial type and group, $F(1, 35) = 1.257$; $p = .291$. Accuracy data can be seen in *Figure 4*.

There was a significant effect of condition on correct RTs, $F(1, 35) = 29.58$; $p < .005$. Responses were slower for local versus global blocks. Trial type had a significant effect on RTs, $F(1, 35) = 45. 391$; $p < .005$. Reaction times were fastest for the compatible trials and slowest for the incompatible trials. There was not a significant main effect of span, $F(1, 35) = 1.227$; $p = .276$ and the condition by group interaction was not significant, $F(1, 35) = .109$; $p = .743$. There was a significant interaction between condition and trial type, $F(1, 35) = 5.989$; $p < .005$ but there was not a significant interaction between trial type and group for RTs, $F(1, 35) = 1.125$; $p = .331$. The 3-way interaction between condition, trial type and group was also not significant, $F(1, 35) = 2.310$; $p = .107$. Reaction time data can be seen in *Figure 5*.

Stop-Signal

For the results for the Stop-Signal task six one-way ANOVAs were performed which looked at accuracy, reaction times and stop-signal delays. Accuracy between span groups was not significantly different when the stop-signal was present, $F(1, 34) = 3.185$; $p = .084$, or absent, $F(1, 34) = 2.316$; $p = .138$. These results can be seen in *Figure 5*; as noted in the *Method*, the stop-signal variation produced the desired effect of approximately chance level performance (50%) on those trials for both high and low spans. Reaction times between span groups was also not significantly different when the stop-signal was present, $F(1, 34) = 2.578$; $p = .118$, or absent, $F(1, 34) = 1.45$; $p = .237$. This can be seen in *Figure 7.*

For SSD, we looked at two indices of performance: the mean delay over all trials and the delay used on the final trial. Neither of these was found to be significantly different between the two span groups (mean: $F(1, 34) = 1.31$; $p = .261$; final: $F(1, 34) = 1.735$; $p = .197$). Stop-Signal Reaction Time was found by subtracting average SSD from average reaction time on trials with no stop-signal. This variable was not found to be significantly different between the two span groups, $F(1, 34) = .146$; $p = .705$. All of these results can be seen in *Figure 8.*

Discussion

Overall we found no significant differences in our attention control measures between participants with high and low working memory spans. However, as you can see in *Figure 8*, the results that we found for both span groups in the Global/Local task are very similar to those that Navon (1977) found. For the other tasks we also obtained similar results as the original tasks: (a) no-go trials were less accurate than go trials, and that performance worsened in the second block; and (b) stop-signal delay manipulation produced almost exactly a 50% chance of correctly stopping on such trials. This suggests that the tasks were accurately measuring the aspects of attention control that we aimed to measure.

In retrospect, despite numerous examples from our lab and others showing that low spans show worse impairment in specific conditions of controlled attention tasks such as the antisaccade (Kane et al., 2001) and Stroop (Kane & Engle, 2003) paradigms, other research indicates the tasks used here may not be sensitive to individual differences in working memory span. For example, Miyake and colleagues (Miyake et al., 2000; Friedman & Miyake, 2004) have shown in two large-sample studies that neither Operation Span nor Reading Span was related to performance on their versions of the Stop-Signal (r = .13, -.03) or Local/Global (r = -.04, -.03) tasks. Friedman & Miyake (2004) have shown that tasks typically viewed as measuring "inhibition" vary widely in their relationship among each other and with external cognitive constructs such as working memory and intelligence (see also Friedman et al., 2006).

Future studies should examine the different cognitive requirements necessary for the tasks that involve working memory capacity and those that do not. It is apparent that some aspects of attention control and not others affect working memory capacity. Finding out how the demands of these various types of tasks differ will further help us understand what determines working memory capacity.

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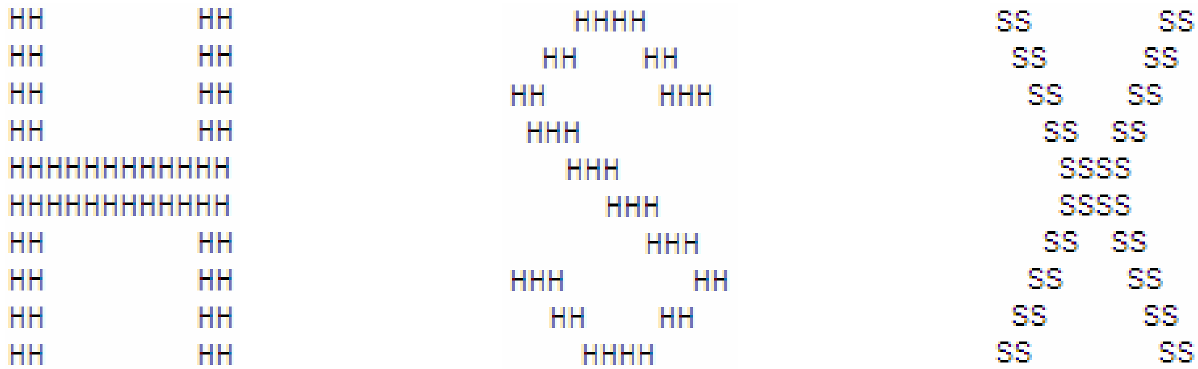

Compatible Incompatible Neutral

Figure 1. Examples of possible stimuli in the Global/Local task. Compatible figures occurred when the large letter was the same as the small letters that formed it. Incompatible figures occurred when the large letter and the smaller letters that make it up were not the same. When the global letters were being responded to, a neutral figure was an H or an S made of small X's. When the local letters were being responded to, a neutral figure was an X made of either small H's or S's.

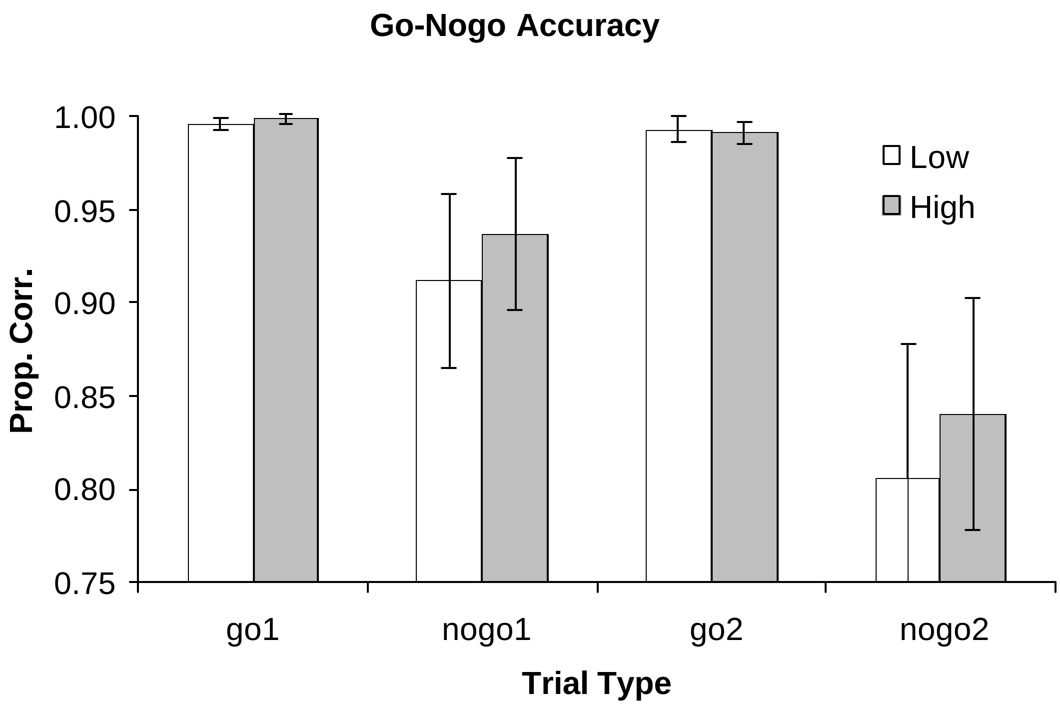

Figure 2. Go-NoGo accuracy between span groups, trials types and blocks.

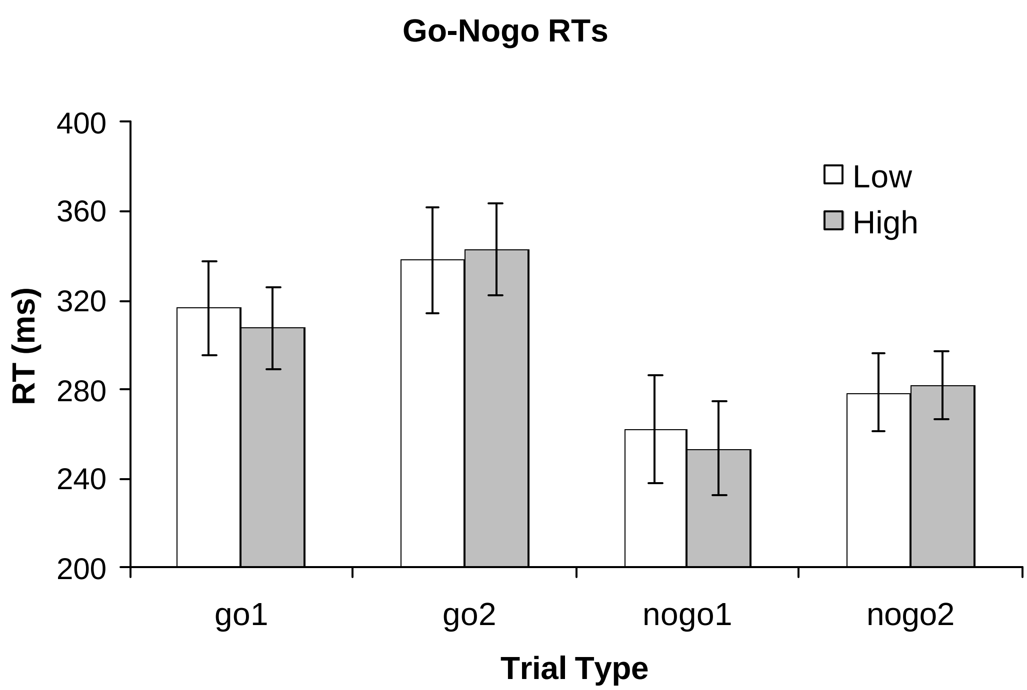

Figure 3. Go-Nogo reaction times between span groups, trials types and blocks.

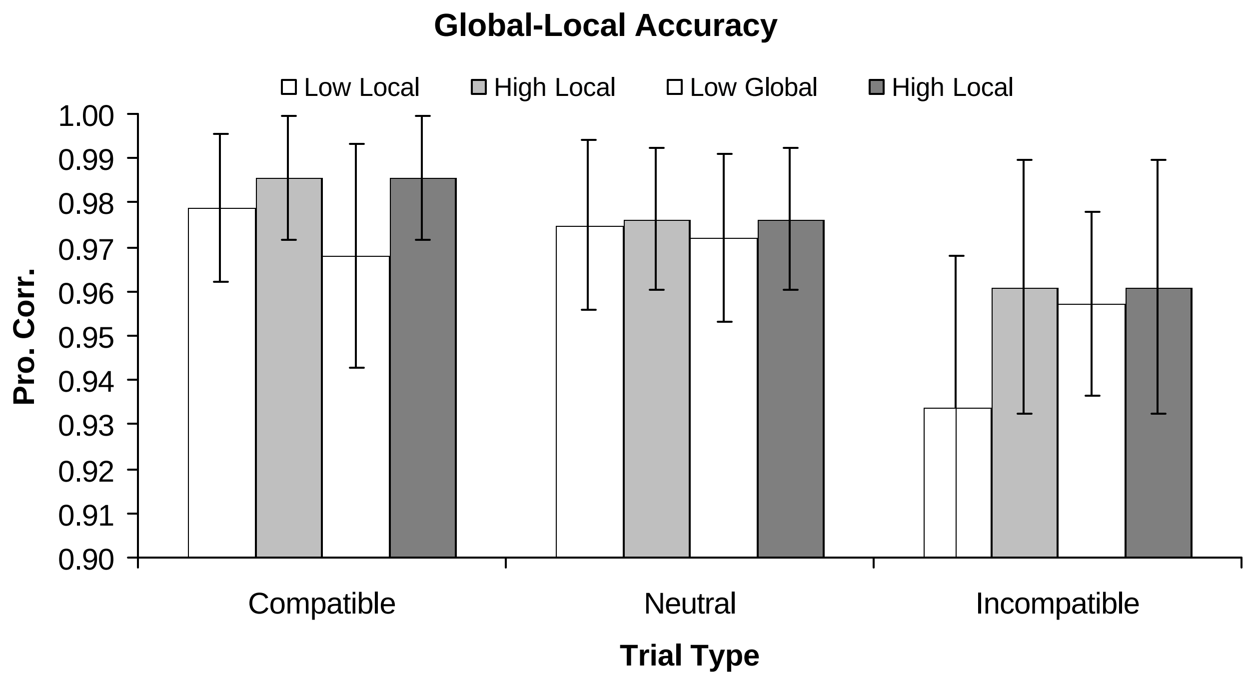

Figure 4. Global-Local accuracy between span group, condition and task order.

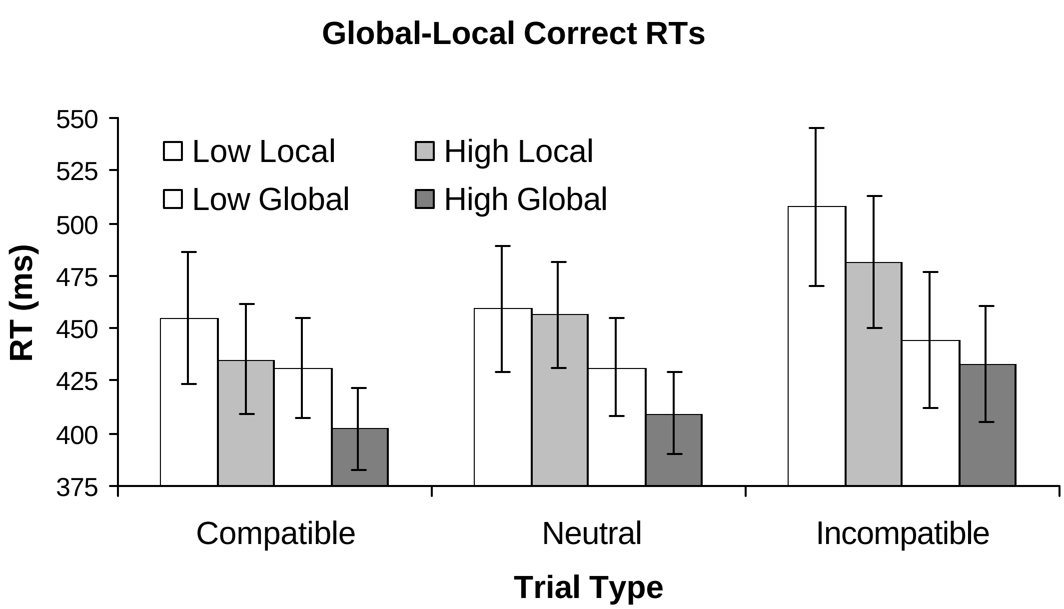

Figure 5. Global-Local reaction times for correct trials between span group, condition and task order.

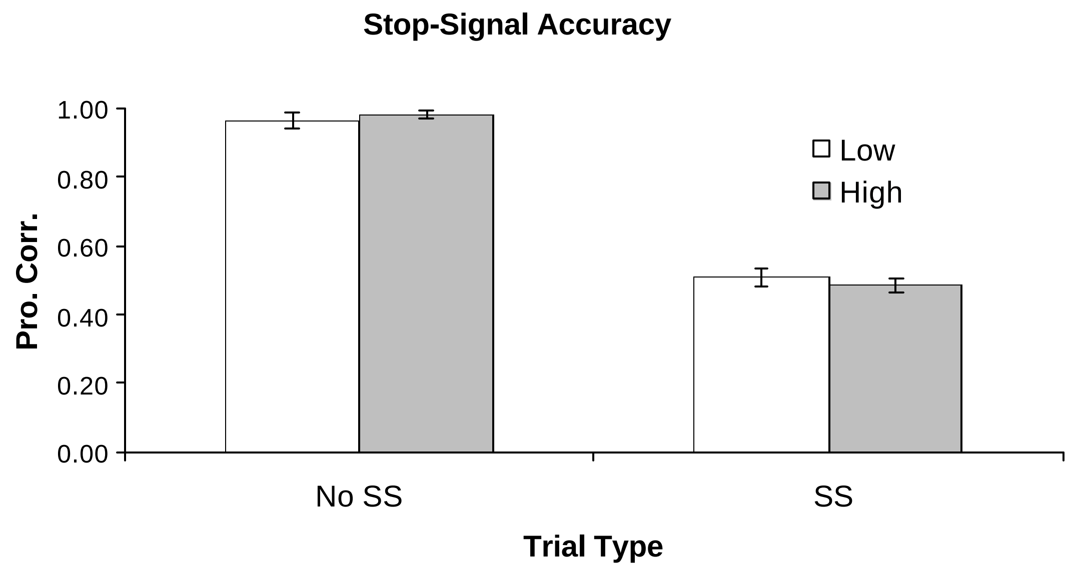

Figure 6. Stop-Signal accuracy between span groups and trial types.

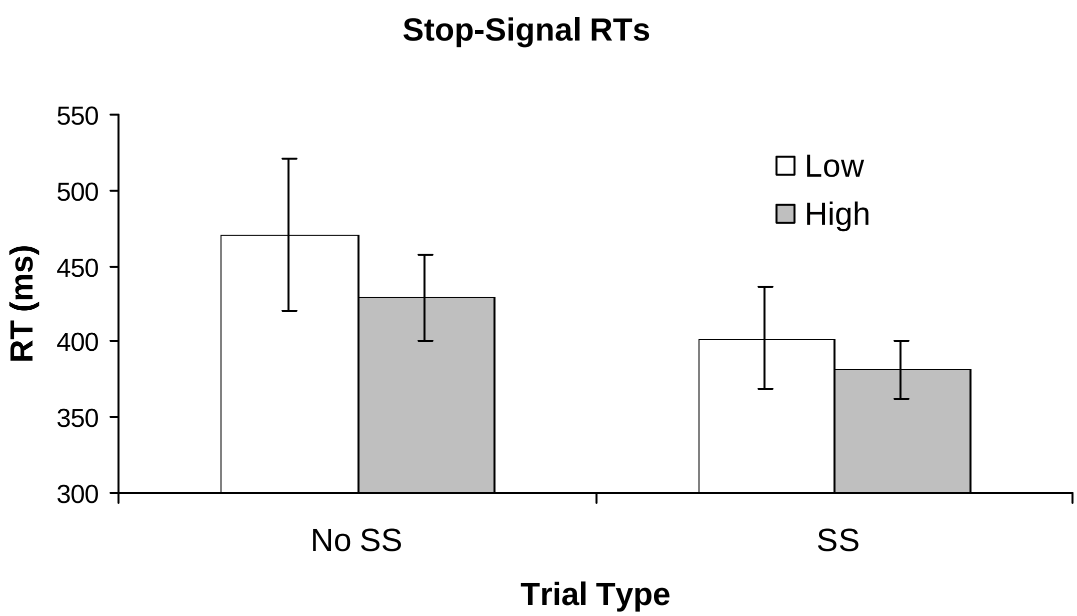

Figure 7. Reaction times between span groups and trial types.

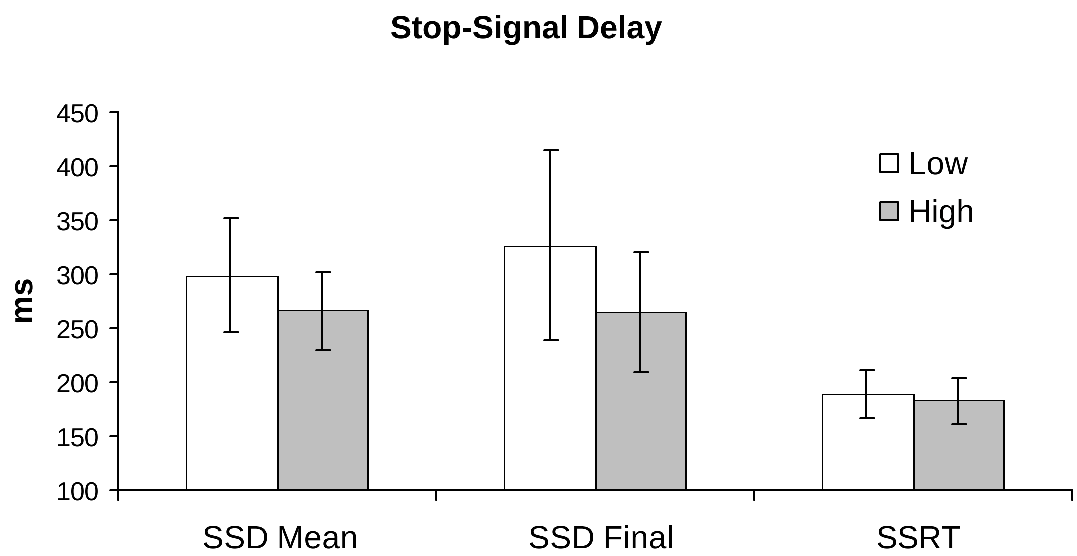

Figure 8. Average Stop-Signal Delay, Final Stop-Signal Delay and Stop-Signal Reaction times between groups.

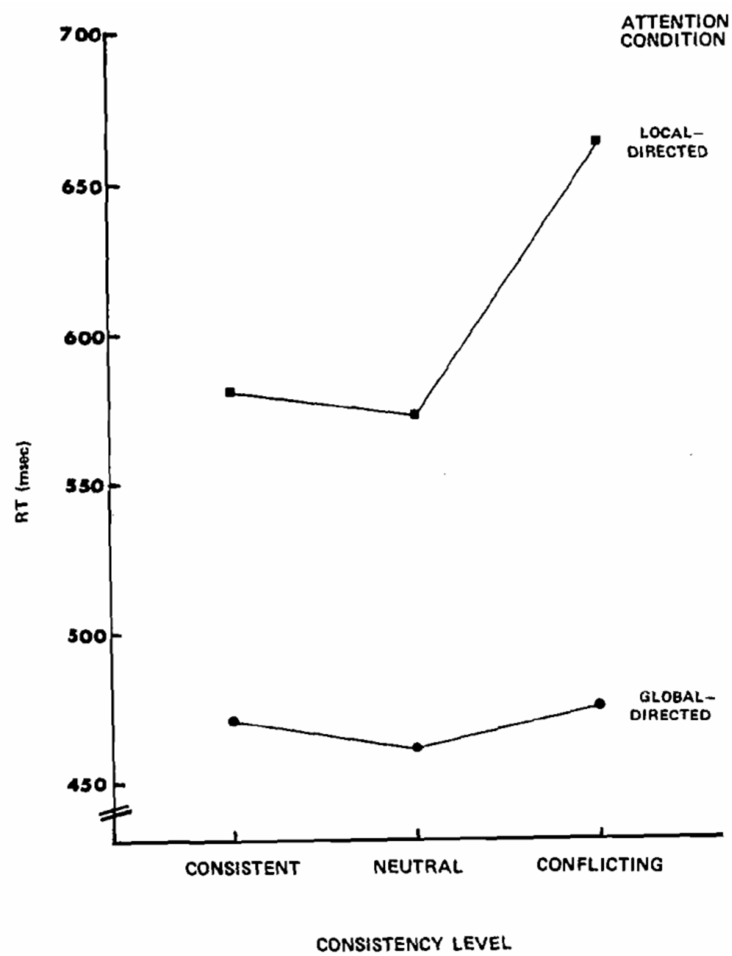

Figure 9a. Navon (1977) found that reaction times were affected most strongly when local figures were being identified and the global and local figures were conflicting.

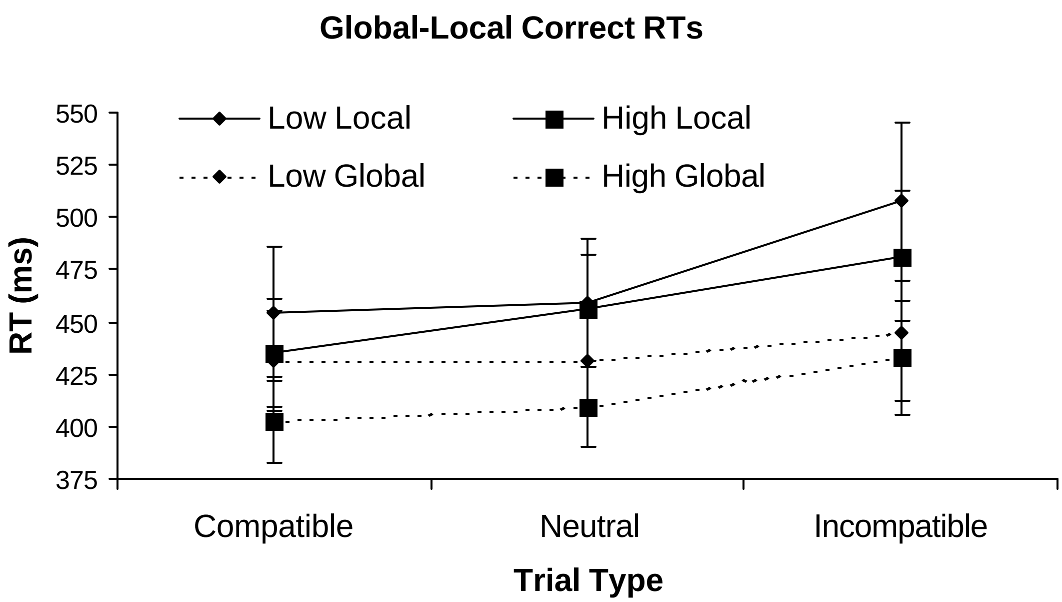

Figure 9b. We found that reaction times were most affected when local figures were being identified and the local and global figures were incompatible. We found the same effects for participants with both high and low working memory spans.