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Working Memory Capacity and Attention Network Test Performance

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SUMMARY

Complex span tasks are predictive of many aspects of behavior, in both experimental and applied areas of cognitive psychology. Our view is that these tasks measure primarily working memory capacity (WMC), which we argue is the ability to control attention. The development of the Attention Network Test (ANT) provided the opportunity to study the relationship between WMC and specific types of attention. Extreme WMC-span groups differed in the executive control network but not in the alerting or orienting networks, supporting the view that individual differences in WMC reflect variation in the ability to control attention. We discuss problems with the design of the ANT that limit its appropriateness for applied research. Copyright © 2006 John Wiley & Sons, Ltd.

We have argued that individual differences in working memory capacity (WMC), as measured by complex span tasks such as Operation Span (OSPAN; Turner & Engle, 1989), reflect primarily the ability to control attention (Engle & Kane, 2004). WMC is most important in situations where there are multiple relevant distractors and/or a prepotent behavior that conflicts with the desired target behavior. Support for this view comes from our research studying the importance of WMC on tasks such as dichotic listening, Stroop, and antisaccade (see Engle & Kane, 2004, for review).

INDIVIDUAL DIFFERENCES IN WMC

Although most of our research has focused on studying WMC on various cognitive tasks, increasing evidence suggests that individual differences in WMC are important in other areas of psychology as well. Performance on complex span tasks predicts behavior in many different situations, including following directions, writing, note-taking, computer-language learning, and bridge playing (Engle & Kane, 2004). In addition, research in the social domain has shown that WMC is related to the ability to handle life stress and stereotype threat (see Redick, Heitz, & Engle, in press, for a review).

More germane to the topic of this special issue, we propose that individual differences in WMC are related to issues such as false memory, imagination inflation, and counterfactual thinking. Interest in cognitive individual differences variables related to these topics has

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grown recently, as evidenced by the special issue of this journal dedicated to individual differences in suggestibility in December of 2004. Loftus (2004) stated that, ‘some individuals, such as those who tend to have lapses in memory and attention, are more susceptible to imagination inflation than others’ (p. 145). Three related findings involving WMC support this idea.

First, Goldinger, Kleider, Azuma, and Beike (2003) studied the effect of counterfactual thinking in mock-jury situations in which participants were asked to decide responsibility and award monetary compensation in different scenarios. Although overall monetary compensations were lower in counterfactual-thought induced situations compared to control situations, participants with low WMC-spans (LS) awarded significantly smaller judgments than those with high WMC-spans (HS) in the counterfactual scenarios when judgments were made under a secondary cognitive load. The authors argued that LS were unable to suppress the irrelevant counterfactual thoughts when making their decisions. Garry and Polaschek (2000) noted the relationship between counterfactual thinking and imagination inflation; as applied to the scenarios in the Goldinger et al. study, because LS are worse at suppressing such thoughts, they may have actually changed their memory of the cases, and therefore at decision time based their judgments on their version of the events instead of the actual facts. Watson, Bunting, Poole, and Conway (2005) examined WMC and false memory using the Deese–Roediger–McDermott paradigm, in which participants are given lists of semantically related words for immediate free recall. They found that when warned about the nature of the task, LS were more likely to recall the nonpresented lure words compared to HS. Finally, Bottoms, Quas, and Davis (in press) reported the results from a study of children comparing interviewer styles on eyewitness reports. They found that LS were more suggestible to leading questions, but only in the nonsupportive condition. One interpretation is that this type of interview style intimidated participants, and that the LS children were especially impaired by the load that this stress caused while trying to answer the interviewer’s questions (see Redick et al., in press, for similar effects of load on LS).

In addition to the high-order relationships just described, we have conducted several studies examining individual differences in WMC in a variety of low-level visual attention tasks. The goal of these studies is to specify the exact relationship between WMC and attention and the situations in which WMC is important for performance. From these studies, we have shown that HS and LS (a) are equivalent when making reflexive saccades but differ when preventing a prepotent saccade in order to make a controlled eye movement (Unsworth, Schrock, & Engle, 2004); (b) differ in the manner of attention allocation in demanding situations, with HS flexibly allocating their attention in an object-based manner and LS using a fixed location-based distribution of attention (Bleckley, Durso, Crutchfield, Engle, & Khanna, 2003); and (c) differ in the rate of attention constraint when processing incompatible flanker displays of letters (Heitz & Engle, 2005).

ATTENTION NETWORK TEST

The Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002) was predicated on the idea that aspects of attention are distinguishable and that individuals can differ on the separate functions. The types of attention are: (a) the *alerting* network, related to maintaining readiness; (b) the *orienting* network, responsible for selecting the region of space or the channel to be attended; and (c) the *executive control* network, involved in resolving conflict among possible actions. Fan et al. argue that these different types of attention are independent based on behavioral and neuropsychological evidence that supports distinct attention functions. Fan et al. claim that the ANT has many advantages as a diagnostic tool, including its relatively quick (30 minutes) and easy (children and nonhuman primates can be assessed) administration. Posner and Rothbart (2005) argue that using the ANT to identify attention deficiencies can lead to training programs designed specifically to improve that aspect of attention.

The ANT combines multiple warning cues (Figure 1a) and flanker displays (Figure 1b) in order to study these different types of attention. The manipulations of cue and flanker type allow the calculation of response time (RT) difference scores assumed to represent the three attention networks. The alerting network, as stated earlier, is important in sustaining a ready state. Staying alert on a task is aided by providing participants with a warning at the beginning of the trial that precedes the target by a fixed amount of time. In the ANT, alertness is compared in situations where participants receive a warning cue letting them know of an upcoming flanker display to a condition where participants do not receive a warning. The alerting network score is calculated by subtracting the double cue conditions from the no cue conditions. These cues are used because the double cue provides temporal information regarding the upcoming flanker display that the no cue condition does not, but

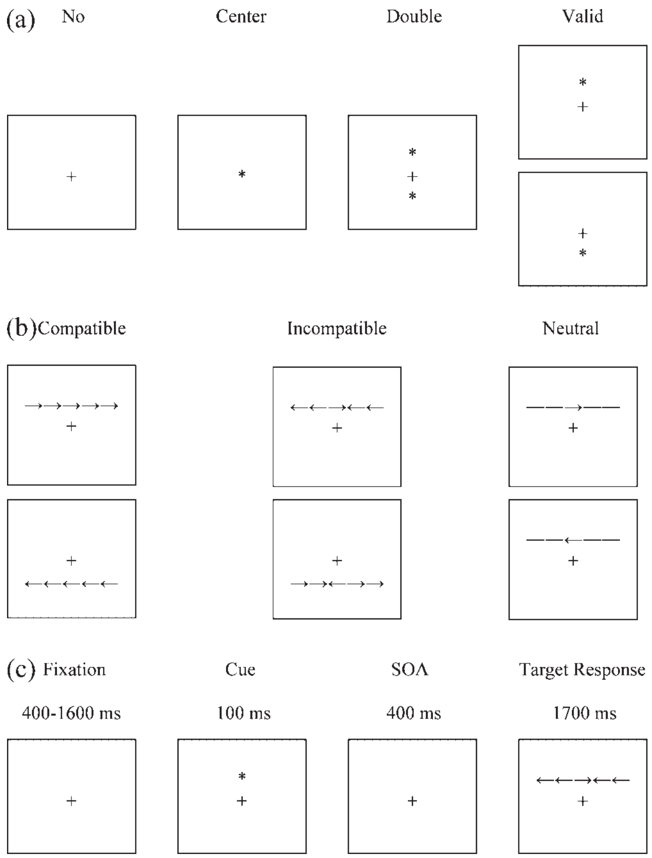

Figure 1. Attention Network Test (ANT) design and procedure; (a) the four warning cue conditions; (b) the three flanker conditions; (c) an example of the time course of a valid incompatible trial

both cue conditions are thought to represent a diffuse allocation of attention. The orienting function of attention is involved in selecting the correct input stimulus for further processing. Orienting in the ANT involves moving attention from fixation to the center arrow of the flanker display. For this reason, the orienting network score is calculated by subtracting the valid cue condition from the center cue condition. The valid cue captures attention to the appropriate stimulus location for the upcoming flanker display, but in the center cue condition, attention will have to move to the flanker display when it appears either above or below fixation. Executive control is invoked when the situation requires conflict resolution, a function that has been linked to WMC (Engle & Kane, 2004). The executive control network score is calculated by subtracting the compatible flanker condition from the incompatible condition.[1] The distractors surrounding the center target in the incompatible condition result in more interference in the response selection process compared to the compatible condition.

The design of the ANT makes at least three assumptions about how attention functions.[2] The first two are strongly related to the additive-factor method proposed by Sternberg (1969), who argued that, 'there are successive functional stages between stimulus and response, whose durations are additive components of the RT' (p. 277). A secondary assumption is that these successive stages operate independently, as proposed by Fan et al. (2002). However, this concept of how attention works is in contrast to other models of visual attention in which mechanisms overlap or interact (Awh & Jonides, 2001; Vidyasagar, 1999). In addition, Fan et al. subscribe to the spotlight-theory of attention (Posner, Snyder, & Davidson, 1980), when attention can be allocated in an object-based manner (Duncan, 1984). While these theories make similar predictions regarding the effect of attention (attended stimuli benefit from increased activation), Duncan and others have shown that attention does not necessarily take a specific shape (e.g., a spotlight) in all situations.

The current experiment tested HS and LS on the ANT. The main goal of the experiment was to determine whether group differences in WMC correspond to differences in the three attention functions measured by the ANT. Based on previous work and our view of WMC, we predicted that high spans would be better at controlling their attention in the incompatible flanker condition, which would result in a span-group difference in the executive control network. Span-group predictions involving the alerting and orienting networks were less clear.

METHOD

Participant screening for WMC

All participants were first screened on the OSPAN task (Turner & Engle, 1989) to assess WMC. In this task, participants solve mathematical operations while also remembering unrelated words for recall. The set size varied from two to five, with three presentations of each set size, and items were scored as correct if all words in the given set were recalled in the correct order.

[1]Following Fan et al. (2002), we also calculated the executive control network difference score by subtracting compatible trials from incompatible trials. Using neutral trials instead of compatible trials yields similar results.
[2]We thank a reviewer for helping to improve this point.

Participants

The participants included undergraduates from several area colleges and Atlanta community volunteers. Fifty-four participants, ranging in age from 18 to 35 years, completed the study. Participants were 26 HS and 28 LS. All participants received either course credit or monetary compensation for their participation.

Design

The design was a $2 \times 4 \times 3$ mixed-model factorial, with span (high, low) as the between-subjects variable, and warning cue (no, center, double, valid) and flanker (compatible, incompatible, neutral) as the within-subjects variables.

Procedure

The materials and procedure for the ANT followed from the information that has been previously published on this test (Fan et al., 2002). An example of a valid (cue) incompatible (flanker) trial is given in Figure 1c.

The task on each trial was to classify the central arrow as either pointing left or right. Participants responded via one of two buttons labeled *L* and *R*, using their left index finger for leftward pointing arrows and their right index finger for rightward pointing arrows. The flanker display appeared either above or below the fixation cross, and remained on screen until either the participant made a response or 1700 milliseconds passed.

Each participant was tested individually. All participants completed 12 practice trials with accuracy feedback before performing 3 blocks of test trials, which did not include feedback. There were 48 different trial types (4 cues $\times$ 3 flankers $\times$ 2 target locations $\times$ 2 target directions). Each trial type was completed twice in each block, providing the 288 total test trials.

RESULTS

All analyses were conducted with an alpha level of 0.05. Only correct trials were included in the RT analyses. Trials were collapsed across target location and target direction to yield 24 trials of each cue by flanker combination.

Participants

Two participants (1 HS and 1 LS) were removed from further analyses based on their low overall accuracy. Therefore, all analyses were based on 25 HS and 27 LS. The mean OSPAN scores for the HS and LS were 25.52 ($SD = 6.77$) and 5.74 ($SD = 2.40$), respectively.

Accuracy data

Overall, the accuracy rates on the ANT were identical for HS ($M = 0.98$, $SD = 0.02$) and LS ($M = 0.98$, $SD = 0.02$). Due to the lack of span group effects in the accuracy data, our focus will be on the RT data.

Table 1. Means of the median RT (milliseconds) and standard deviations of participants with high and low spans in each condition of the ANT

	Cue			
Flanker	No	Center	Double	Valid
High spans ($n = 25$)				
Compatible	535 (61)	495 (64)	484 (59)	452 (55)
Incompatible	612 (73)	592 (66)	588 (63)	528 (62)
Neutral	521 (50)	491 (66)	475 (49)	443 (47)
Low spans ($n = 27$)				
Compatible	602 (113)	556 (103)	551 (108)	505 (99)
Incompatible	706 (125)	695 (142)	690 (129)	609 (131)
Neutral	569 (89)	546 (101)	542 (93)	494 (88)

RT data

A 2 (span) $\times$ 4 (cue) $\times$ 3 (flanker) ANOVA was conducted on the RT data for correct trials only. Means of the median RTs and standard deviations for each of the conditions are listed in Table 1.

The data showed that HS were faster overall, and that incompatible trials were slower for both groups. In addition, the valid cue trials were fastest among the different warning cues, while the trials with no warning cue were slower than the remaining types of warning cue trials.

These conclusions were supported by the results of the ANOVA on the RT data. There were main effects of span, $F(1, 50) = 9.09$, partial $\eta^2 = 0.15$, cue, $F(3, 150) = 218.62$, partial $\eta^2 = 0.81$, and flanker, $F(2, 100) = 238.74$, partial $\eta^2 = 0.83$. However, the span main effect was qualified by a significant flanker x span interaction, $F(2, 100) = 6.58$, partial $\eta^2 = 0.12$. The cue x span interaction was not significant, $F(3, 150) = 2.24$, partial $\eta^2 = 0.04$. In addition, there was a significant cue x flanker interaction, $F(6, 300) = 8.65$, partial $\eta^2 = 0.15$. The three-way interaction was not significant, $F(6, 300) < 1$, partial $\eta^2 = 0.02$.

Difference scores

In order to interpret the interactions involving the span groups, one-way ANOVAs were calculated separately for the alerting, orienting, and executive control networks, with span group as the between-subjects factor. The difference scores for each span group are shown in Figure 2.

HS and LS did not differ in alerting, $F(1, 50) = 2.66$, partial $\eta^2 = 0.05$, nor in orienting, $F(1, 50) = 2.55$, partial $\eta^2 = 0.05$. However, as predicted, the span groups did differ in executive control, $F(1, 50) = 6.96$, partial $\eta^2 = 0.12$. LS ($M = 121.57$, $SD = 56.26$) demonstrated a larger difference between incompatible and compatible trials compared to HS ($M = 88.36$, $SD = 29.25$), which resulted from LS being considerably slowed by incompatible flankers.

DISCUSSION

WMC and the ANT

The results support the executive attention view of WMC because span group differences were seen only in the executive control network, which was hypothesized to reflect the

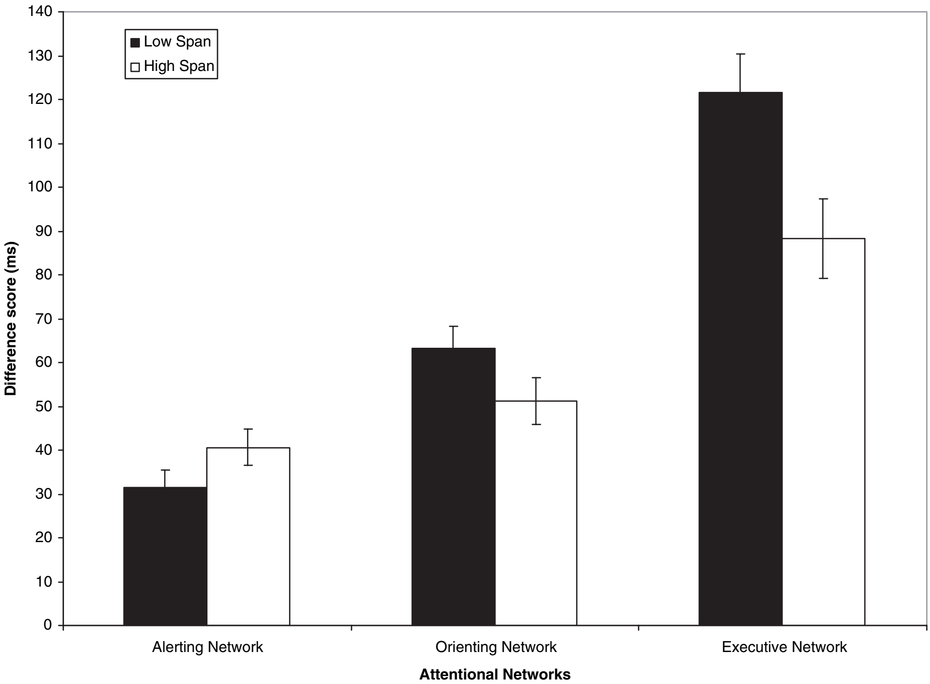

Figure 2. The ANT difference scores for the high and low span groups; the error bars represent plus or minus one standard error of the mean

ability to control attention and resolve conflict, and not in networks of attention related to alerting and orienting functions. Several problems with the ANT design, outlined below, limit the strength of our conclusions. One potential problem is the difference between the span groups in overall RT (HS: $M = 517.92$, $SD = 57.05$; LS: $M = 580.83$, $SD = 100.67$). Although previous experiments have found differences between span groups in overall RT (Unsworth & Engle, 2005), overall RT differences are more commonly a problem in developmental research (Faust, Balota, Spieler, & Ferraro, 1999). The result is that group differences in overall RT can lead to spurious interactions with between-subjects and within-subjects variables. That is, a significant main effect of group can make interpretations between the groups on an experimental manipulation (e.g., a significant group by treatment interaction) more tenuous. Additionally, because the difference scores are a between-groups comparison of within-subjects variables, they are prone to the same interpretability problems. Part of this problem arises from the lack of a true baseline condition in the ANT. Nonetheless, other researchers using the ANT have compared groups on their network scores despite group differences in overall RT (Rueda et al., 2004).

Problems with the design of the ANT

Other properties of the ANT raise questions about its effectiveness as a useful measure. First, because the interpretation of the ANT is based on difference scores, the problem of low reliability in difference scores in general (Lord, 1963) is problematic in attempting to assess separate attention functions. Fan et al. (2002) reported test-retest correlations for each network effect in the range of $r = 0.52$–0.77. Rueda et al. (2004) studied the development of attention networks in children ranging from 6 to 8 years of age and 'found no significant correlations between the original network scores and their repetition 6.5 months later' (p. 1038). In addition, Beran, Washburn, and Kleinman (2003) failed to replicate the alerting and orienting network effects in separate tests of children ranging from 6 to 17 years of age and in two male rhesus macaques.

The main evidence Fan et al. (2002) cite for the independence of the attention networks is based on the absence of significant correlations between the respective difference scores. An alternative interpretation suggests the lack of significant correlations may occur because their calculation is based on unreliable measures (a possibility also noted by Rueda et al., 2004). In addition, basing the claim of independence on nonsignificant correlations relies on accepting the null hypothesis.

We also question whether or not the assumptions of the ANT laid out in the introduction are appropriate. The effectiveness of the ANT to assess separate and independent attention networks is doubtful considering the significant cue *x* flanker interaction seen in both Fan et al. (2002) and the present study. In addition, participants might respond differently to the conditions used to calculate the difference scores in ways that are not directly tied to the type of attention that score is assumed to represent. For example, Bleckley et al. (2003) showed that individual differences in WMC are related to the manner in which visual attention is allocated. Thus, use of the double cue condition to calculate alerting efficiency may be problematic to compare the span groups. Based on Bleckley et al., LS are likely to correspond to the Fan et al. assumption that a unitary spotlight of attention expands to encompass both cues in the double cue condition; however, HS may be dividing their attention to the two cues, and any differences between the no cue and double cue conditions can no longer be localized specifically to differences in alerting.

CONCLUSION

In a low-level attention task, we found individual differences in WMC were predictive of performance in situations requiring controlled attention. At this point, the limitations of the ANT mentioned above are problematic for the widespread application of this test. Although we are intrigued by the idea of diagnosing attention deficiencies and then improving attention via training (Posner & Rothbart, 2005), uncertainty remains whether the current version of the ANT should be used in more applied settings. The issues with the ANT notwithstanding, we propose that future work in the areas mentioned in this paper will be aided by a combination of differential and experimental psychological approaches (Cronbach, 1957).

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