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13. ABSTRACT (Maximum 200 words) This project conducted a series of studies designed to measure and understand the nature of individual differences in working memory capacity and the extent to which such differences result from differences in the ability to control attention. Tasks are described that have good reliability and validity for measuring working memory capacity. Studies are described suggesting that individual differences in speed of processing may reflect differences in the speed of attention focus and shifting.

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We (Engle et al., 1999; Engle, 2000) view working memory as a system consisting of a subset of highly activated long-term memory units (see Cowan 1988, 1995), a wide array of processes that achieve and maintain activation of those units, and an executive attention component. The executive attention component (or central executive) of working memory is an attentional mechanism used to maintain current task goals, process incoming information, and block external (i.e. environmental distractors) and internal (i.e. other unrelated long-term memory units) interference (Engle, 2000). This idea is similar to controlled processing (Posner & Snyder, 1975; Schneider & Shiffrin, 1977), but is probably better conceptualized as a somewhat narrower concept similar to the Supervisory Attentional System proposed by Norman and Shallice (1986) and the general concept of cognitive control as depicted in computational models of the prefrontal cortex and anterior cingulate regions of the brain (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001). Thus, when we refer to Working Memory Capacity (WMC), we mean the executive attention component of the broader working memory system that is necessary when active maintenance is needed especially in conditions of interference (Engle, Kane, & Tuholski, 1999; Engle, 2000).

The studies reported herein are concerned with examining individual differences in WMC, as measure by complex working memory span tasks, in terms of differences in executive attention and their relation to measures of higher-order cognition, especially fluid intelligence. To this end, our studies rely on both quasi-experimental and large scale correlational designs. For both, we primarily utilize the operation span task (Ospan; Turner & Engle, 1989) which requires participants to solve simple math equations while trying to remember a set of unrelated words. For the quasi-experimental designs, we select only those subjects who fall in the top or bottom quartiles of the Ospan distribution. These participants are then asked to come back and

participant in another experimental session. The correlational studies, however use the full distribution of scores. The studies can be broken down into two broad sections: 1) Studies concerning the relation between individual differences in WMC and low-level attentional abilities and 2) Studies concerned with how performance differences on WM span tasks are related to higher-order cognition.

Studies in the first section include a follow up to our antisaccade studies, demonstrating that latency differences found in previous studies occur under conditions of endogenous orienting, suggesting that high and low WM span individuals differ speed with which they can move the focus of attention. In addition, we report new studies using the Eriksen flanker paradigm demonstrating that high and low span individuals differ in the speed with which they can constrain the attentional focus, rather than a difference in ability per se. A Rate of Attention Constraint (RAC) model is proposed to account for these findings. Our last study in this section concerns the dynamics of the focus of attention. Specifically, participants were required to count big and small squares that appeared one at a time. Trials could either be switch trials in which participants had to switch from one count to another (e.g. from big squares to small squares) or could be non-switch trial in which case, subjects simply updated the current count in the focus. Our reasoning was that the focus is limited to the amount of information that it can hold at any one time and thus a switch is required to update a count that is not currently in the focus of attention. This study demonstrated that updating a count not in the focus of attention requires considerable time over and above that required to update the count currently within the focus. In addition, the results suggest that when the number of switches increases, high and low Wm spans begin to diverge. This suggests that high and low spans differ in the efficiently with which they can move the focus of attention.

Studies in the second section include a study aimed at determining the possible locus of the correlation between measures of WMC and fluid abilities. In this study, we examined the correlation between Ospan and Raven Advanced Progressive matrices in detail to test some basic theories on the relation between WMC and fluid abilities. The study demonstrated that the correlation is not due to differences in the difficulty of problems, the type of rules that must be followed on a problem, or to differences in the amount that can be held in memory. A second study in this section examined the possibility that individual differences in WM span performance is due to differences in the expenditure of effort. Here, we tested high and low span individuals on another WM span task (reading span) and obtained pupil measurements for each subject. Briefly, a body of research suggests that the pupil of the eye is sensitive to variation in mental effort expenditure. In a series of three studies, we concluded that the difference between high and low span performance is *not* due to differences in mental effort. In other words, it is not the case that high spans are those who simply "try" harder.

The last study reported in this section was aimed at modifying operation span so that it would cut down on the time it takes to both run subjects and score their data. In addition, it was our hope to develop a task that could be easily administered in groups, thus allowing for the use of WM measures in other research domains. The modified version of Ospan demonstrated both good reliability and validity.

Automated Ospan and Automated Ravens

Our goal is to create a battery of WMC tasks that are reliable, valid, automated, and therefore easily administered in field, clinic, or laboratory settings. We have begun to test a computerized version of OSPAN that is entirely mouse-driven, requiring no intervention from the experimenter.

Task: The task begins with practice on the memory requirement alone, in which a series of 2-6 letters appear one at a time for 800 ms each. At test, participants see the full set of 12 letters from which the targets were drawn, and they must recall the targets by clicking on them in correct serial order. Accuracy feedback is presented after every trial. Following memory practice, participants practice with math operations. For each operation (e.g. (1 x 2) + 1 = ?), the participant calculates the answer and then clicks the mouse to advance to the next screen. They then see an answer (e.g., 3) and must click on the word True or False onscreen. Feedback follows each response. Following math practice, the program calculates the individuals mean solution time for the equations, and uses this as the solution cut-off time for the subsequent portions of the task. A final practice session has participants perform both the memory and math portions together, just as they will do in the subsequent test session. Participants first see the math operation and, after solving it, they see the letter to be recalled. After the participant completes all of the practice sessions, the program moves on to the real trials, with 3 sets of each set-size ranging from 3-7 items. In our earlier proposal, set-sizes ranged from 2-6, we increased set-size in order to obtain a normal distribution of scores. For the test and final-practice sessions, if any operation is not solved within 2.5 SDs of the practice mean RT, it disappears and the trial is considered an error. Participants must maintain at least 85% accuracy in the math portion of the task to receive a score. After recall for each trial, feedback in the form of number of correctly recalled letters and number of math errors made for that trial is presented. Additionally, in order to make sure that participants are doing their best on the math problems, a cumulative percentage is presented and participants are instructed to keep the percentage above 85%. This change was implemented subsequent to our original proposal because many of our participants were committing many math errors. In providing feedback after each trial, our hope

was to maintain solution accuracy at 85%.

Results: We tested 252 participants. Each completed the standard OSPAN, the automated OSPAN, and a computerized version of the Raven Progressive Matrices test. The correlation between standard and automated OSPAN is .44. The Raven test correlates with standard and automated OSPAN with rs = .41 and .38, respectively. Additionally, a reliability estimate (coefficient alpha) for automated OSPAN suggests that it has good reliability (.78). In addition, we brought participants back to determine the test-retest reliability of the automated OSPAN as well as further test its validity. During a second session, participants received the automated OSPAN task, another spatial reasoning measure (Air Force Officer Qualifying Test: Rotated Blocks) and the reading span (RSPAN) task. The results for 78 participants suggest that the test-retest reliability is good at .83. Furthermore, automated OSPAN correlates with both RSPAN and Rotated blocks with rs = .51, and .23, respectively. Finally, a exploratory factor analysis demonstrated that both versions of OSPAN and RSPAN loaded onto one factor while the two reasoning measures loaded on a separate factor with the two factors correlating at .45.

Poster Presented and the annual meeting of the American Psychological Society.

Operation Span (Ospan) and Ravens Advanced Progressive Matrices

We examined the performance of 160 participants on Ospan and the Advanced Progressive Matrices in order to better determine what accounts for the shared variance between the two tasks. Specifically, we utilized a post-hoc decomposition of Ravens problems and examined how the correlations between the decomposed variables and Ospan. Previous research (Carpenter, Just, & Shell, 1990) has suggested that the shared variance between working memory measures and intelligence measures is due to the differential ability to "hold" items in memory.

Carpenter et al., 1990 showed that the more difficult problems on Ravens are also those problems that carry a heavy memory load. Thus, based on this logic, working memory span measures such as Ospan should correlate better with the more difficult problems than with the easier problems. However, we (Unsworth & Engle, in preparation) found that the point-biserial correlation between solution accuracy for difficult problems with not significantly different than the correlation with easier problems. In fact, grouping problems into quartiles based on their difficulty demonstrated that the correlation for the first three quartiles was fairly constant (e.g. Quartile1 = .32, Quartile2 = .29, Quartile3 = .33). However, the correlation for the last and most difficult quartile was non-significant (Quartile4 = .08). Thus, based on this evidence, it would seem that item variations in difficulty do not account for the shared variance between Ospan and Ravens. Additionally, as a more sensitive test of the hypothesis that the shared variance is due to the number of things that can be held in memory, we grouped problems based on their memory loads according to the classification scheme of Carpenter et al., (1990, appendix). Problems were placed into four different groups: those with 1 rule token (a low memory load), 2 rule tokens, 3 rule tokens, and 4 rule tokens (a high memory load). Once again, based on the logic of Carpenter et al., we should see a linear increase in the correlation with Ospan as memory load increases. However, the results suggest a monotonic decrease in the correlation (e.g. Token1 = .34, Token2 = .28, Token3 = .25, and Token4 = .11). The first three rule tokens show a significant correlation with Ospan, but problems with the highest memory load (Token4) show a non-significant correlation with Ospan. Based on this evidence, we would argue that item variations in memory load do not account for the shared variance between these two tasks. Furthermore, the finding that the correlations remain fairly constant for both item variations in

difficulty and memory load suggests that whatever accounts for the shared variance between the two tasks operates virtually the same on the easiest problems as it does on the hardest problems.

Manuscript submitted for publication to Intelligence

Antisaccade and Endogenous Orienting

We followed up our previous findings with the antisaccade paradigm with endogenous versions of both pro and antisaccade trials. Our primary goal was to determine if the latency difference observed between high and low span individuals on correct antisaccade trials is due to the need to suppress a reflexive orientating response. That is, our previous findings showed high and low spans do not differ on relatively automatic prosaccade trials in terms of latency (in a blocked format), but that low spans are significantly slower than high spans on antisaccade trials. However, when pro and antisaccade trials are intermixed within the same block, low spans are marginally slower than high spans even on prosaccade trials. This suggests the possibility than high and low spans may differ on prosaccade trials but only when endogenous control is required and that this difference in latency can be observed when there is little need for suppression. To better test this, we had 34 high and 34 low spans perform four saccade tasks that varied in their requirements of control and suppression.

Task: Two of the tasks were prototypical exogenous pro and antisaccade. For each trial, participants saw a black screen containing the word "ready" in the center of the screen and 1 centimeter (.6 degrees visual angle) white squares positioned at 11.5 degrees of visual angle to the left and right of center. At the start of each trial, the word "ready" was presented in the center of the screen for 1500 ms to warn the participant that a trial was about to begin. A fixation point (a white + sign 1 centimeter by 1 centimeter) then appeared for a period that varied unpredictably

between 600 and 2200 ms in 100 ms increments. In the exogenous conditions, following the wait period, one of the squares flashed for 600 ms, while the fixation point and the other square remained on the screen. In the endogenous conditions, however, the fixation point was replaced by an arrow pointing to either the left or the right of the screen for 600 ms.

In the exogenous antisaccade task, participants were required to make their first eye movement toward the square opposite the flashing square. In the exogenous prosaccade task, participants made a saccade towards the flashing square. In endogenous antisaccade task, participants were required to make a saccade to the box in the opposite direction that the arrow was pointing. In the endogenous prosaccade task, the participant made a saccade towards the box that the arrow was pointing at. After the target flashed for 600 ms or the arrow remained on screen for 600 ms, the targets and center fixation point were removed, and the words "left" or "right" appeared at the correct target location. The target word then remained on the screen for 1500 ms. Following presentation of the target word, the participant was given feedback on whether their first eye movement from the center was correct or not. After 1500 ms of feedback, the next trial began.

Within each 75 trial block, the target position was random and equally likely to occur to the left or right of center. Participants completed 4 sets of 75 trials: two prosaccade sets, two of antisaccade, two exogenous sets (one for pro and one for anti) and two endogenous sets so each participant completed 150 prosaccade and 150 antisaccade trials as well as 150 endogenous and 150 exogenous trials during the experiment. The sole dependent measure was an eye movement. Results: Latency was computed as the amount of time between the onset of the cue and the start of fixation in the area of interest. Only latencies of correct saccades were included in the analyses. The results suggest that high and low span individuals differ in latency in those

conditions that require voluntary generation of a saccade but do not differ in situations where relatively automatic saccades can be generated. That is, there was a significant span by saccade type (automatic vs. voluntary) interaction, indicating that span differences only emerge in conditions requiring the voluntary control of an eye movement. Furthermore, the results demonstrate that high and low span differences in latency are not purely a function of the need to suppress a reflexive saccade. Indeed, looking only at prosaccade trials, the results indicate that low spans are less proficient on endogenous prosaccade trials than are high spans. That is, the difference between exogenous and endogenous prosaccades was greater for low spans (M difference = 52 ms) than for high spans (M difference = 27 ms). Thus, high and low span differences in saccade latency occur even when the inhibition of a pre-potent response is not necessary. Together with our previous antisaccade findings, the present results suggest that although high and low spans differ in their ability to effectively suppress task irrelevant stimuli and responses, this is not the sole difference between these groups. Rather, it seems that high and low spans differ in their ability to utilize endogenous control to maintain and achieve task goals.

Manuscript submitted for publication to Journal of Experimental Psychology: Learning, Memory, and Cognition.

Attentional Switching and Updating in Working Memory

We tested 26 low spans and 28 highs spans on a version of Garavan's (1998) attention switching task to determine the role of WMC in an attention switching and updating. Participants were required to count big and small squares and keep a running count of each type of square. The idea being that in some situations the size of the focus of attention reduces to only 1 item (count)

and thus attentional switches must be made from count to count. Updating the current count should be faster than updating the other count, thus demonstrating that attention had to be switched to the new count. Furthermore, we manipulated the frequency of switches (low, medium, and high) in order to determine how efficient attentional switching is. With more switches it is possible that it will take longer to direct the focus than in conditions of relatively few switches. Furthermore, WM span differences may emerge when many switches are required. The aim was to better understand the dynamics of the focus of attention.

Task: Subjects saw a fixation point on screen for either 150, 300, or 600 ms followed by either a large or a small square. The subject's task was count the number of big and small squares they saw. With the presentation of a square the subject added the square to the current count and rehearsed the other count. For example if a subject has already seen 3 big squares and 3 small squares and is presented with a big square, the subject would say 4 big and 3 small. The subject would then press the space bar and the fixation point would again appear and then a new square. The space bar registered the time it takes to update the current count in ms. At the end of a trial a screen would appear asking the subject how many big squares they saw followed by a screen asking how many small squares they saw. Here, we recorded the accuracy of the counts.

The task consisted of 5 practice trials and 45 real trials. A trial consisting of between 11-15 (585 total squares) (420 non-switch trials and 165 switch trials) squares and the two accuracy screens. We manipulated the frequency of switches that subjects would have to make. That is, the presentation of a square that was different from the preceding square. Frequency was either low, medium, or high. Low frequency trials consisted of only 1 switch. For medium frequency trials the number of switches was determined by the following equation: # of switches = # of squares / 4. For high frequency trials: # of switches = # of squares / 2. Thus, on low frequency

trials there was only 1 switch, on medium frequency trials 25% of the trials required a switch, and on high frequency trials, 50% of the trials required a switch. Thus, the design of the study was a 2 (Span: high vs. low) x 2 (Switch: yes vs. no) x 3 (Frequency: low, medium, and high) x 3 (Rsi: 150, 300, 600).

Results: The results suggest that switching to a new count in memory takes longer than updating the current count (i.e. approximately 500 ms.). Additionally, as the frequency of switches increases so does RT. The two factors also interacted, suggesting that as switching frequency increases, RT's for non-switch trials increase linearly, while RT's for switch trials change only slightly. In terms of WM span differences, the results suggest that high and low spans do differ in their "switch cost." However, as the frequency of switches increases, low spans RT continues to increase but high spans RT plateaus. This suggests that when many attentional switches are required, low spans are less efficient than high spans in moving the focus of attention to the correct count in memory. The results suggest that we cannot store and update two counts in memory, but must switch between them. Updating the current count results in significantly faster RT's than updating a new count. Furthermore, increasing the frequency of switches increases RT, but mostly for non-switch trials. That is, updating the current count gets slower as the number of switches increases. Subjects are probably being more cautious (slower) as frequency increases and thus take less of a hit than on low frequency trials. In addition low spans are less efficient than high spans in moving the focus of attention.

We are currently getting ready to run a second experiment further testing the dynamics of the focus of attention. For the second experiment, subjects will have to hold and update 3 separate counts in memory (squares, triangles, and circles) at medium and high frequencies. This will allow us to better examine the role of attention switching between highs and lows by

making the task more complex and hopefully increasing differences. It will also allow us to better examine the notion of equal access in WM. That is, we can examine whether or not the two counts not in the focus have the same accessibility or whether there is a continuum such that switch costs are largest for those items that were updated the farthest back in time.

Working memory capacity and mental effort

In two previous studies, we evaluated the hypothesis that the difference between high and low span subjects in working memory capacity tasks is due to differences in mental effort. That is, one simple uninteresting alternative explanation is that high spans are simply those individuals who "try" harder during task performance. This of course neglects the observation that highs and lows differ in meaningful and predictable ways; still, it is a hypothesis that needs evaluation. We used task-evoked pupillary responses as a dependent measure. A body of research suggests that the pupil of the eye indexes mental effort (Hess & Polt, 1964; Kahneman & Beatty, 1966) in a roughly linear fashion (as mental effort increases, so does pupil size). In Experiments 1 and 2 high and low spans performed a modified version of the reading span task while their pupils were measured. E1 included no feedback, while E2 included feedback. For both studies, although highs and lows differed in reading span performance, their pupil sizes were not significantly different. However, for both groups, pupil size increased as a function of memory set size. An additional interesting observation was a difference in baseline, or tonic, pupil size, with high spans having approximately 1 mm larger pupils than low spans, even before the task began.

In Experiment 3, we included a stronger, monetary manipulation. We wondered whether increasing incentive would increase both high and low span performance/pupil size or whether it

would affect only the low spans. To this end, we paid participants "bonus money" based on their task performance. The task kept a running average for each trial, and participants could see how much they could earn on each trial, and subsequently, how much they did earn. A participant could earn up to an additional $20.00 if perfect performance was attained (in addition to the $20.00 they earned regardless of performance).

We found that the monetary incentive was significant in increasing both performance and tonic pupil sizes, when compared to E1 and E2, but that this increase was in the same proportion for both high spans and low spans. However, phasic, task-related pupillary responses were again not significantly different for high and low span subjects. In other words, it was not the case that high spans "worked" any harder on the task than did low spans.

We take these results to mean that the observed difference between high and low span subjects on working memory capacity tasks is not due to differences in mental effort.

Individual differences in working memory capacity and visual attention

Kane, Bleckley, Conway, & Engle (2001) and Unsworth, Schrock, & Engle (submitted) showed that low span subjects are both slower and more error prone in antisaccade performance. In this task (particularly the Unsworth et al. study), participants made a saccade either towards (prosaccade) or away from (antisaccade) a flashing exogenous cue. The results were couched in terms of goal-neglect and interference resolution. However, it is also the case that when performing an antisaccade, one must plan and execute a controlled saccade, unlike the prosaccade condition, where attention is automatically drawn to the cue. Given that the eyes follow attention, and not the reverse, it is thus likely that in the antisaccade condition, an attentional spotlight needed to be effortfully oriented to a position in the visual field. The span

differences we observed were clearly consistent with our theory that working memory capacity reflects one's capability for attentional control. Although this is suggestive of possible differences in visual attention ability, the antisaccade task is not optimal for evaluating this hypothesis.

Bleckley, Durso, Crutchfield, Engle, and Khanna (in press), and Bleckley & Engle (submitted) reported rather striking differences between high and low span subjects in the Egly & Homa (1984) task. Briefly, Bleckley et al. (in press) and Bleckley & Engle (submitted) found that while high spans are able to configure their attention in the shape of a ring, low span subjects resorted to an allocation consistent with an "attentional spotlight." Interestingly, both high and low span subjects exhibited a ring-shaped attentional allocation when an exogenous cue relieved them of the need to actively and effortfully configure attention.

In a series of studies, we evaluated possible span differences in an even lower-level aspect of visual attention. In the Eriksen flanker paradigm (Eriksen & Eriksen, 1974), subjects must respond to a central letter flanked on either side by a response-incompatible distractor. It is thought that to perform this task, attention (often described in terms of a "spotlight") must be constrained to the central letter, effectively filtering the flanking letters.

Given our previous studies suggesting that highs and lows differ in their ability to control visual attention, we reasoned that span differences would emerge in the flanker task in one of two ways. The ability hypothesis posits that high spans are better able to constrain, or shrink, their attentional spotlight. Note that this hypothesis suggests a lower bound on the size of attentional allocation. The rate hypothesis, in contrast, suggests that highs and lows have equivalent abilities to constrain attention, but high spans constrain their attention faster than low spans.

To evaluate these competing hypothesis, 15 high spans and 15 low spans performed the Eriksen flankers task with compatible (HHHHH or SSSSS) and incompatible (HHSHH or HHSHH) letters. Trials were randomly compatible or incompatible (i.e., 50/50). The above hypotheses required a more extensive analysis of performance at a number of points in processing. In order to widen the usable response time distribution, we imposed response deadlines of from 700 to 200 ms, in 100 ms increments. The deadline conditions were blocked, beginning with the 700 ms condition continuing downwards to 200 ms.

Using a vincentizing procedure, we computed 10 ntile bins of each subject's rank ordered RTs, separately for compatible and incompatible trials. The results for incompatible trials are presented in FIGURE X. A number of interesting patterns are present. First, when responses are very fast (bin 1), responses are at chance. At somewhat longer RTs (bins 2-4), responses are significantly below chance. This finding is important, because it supports a model of flanker performance whereby attention begins a trial diffuse, encompassing the entire flanker array. As time goes on, the attentional spotlight begins to contract. Thus, when processing is cut short at these bins, the spotlight has begun to contract, but still includes distractor letters. These letters provide more evidence in favor of the opposite response, leading to responses that are more likely to be incorrect. Third, at long RTs, accuracy rates are asymptotic and not significantly different for high and low span subjects. This last observation discounts the ability hypothesis, because if highs and low differed in the ability to constrain attention, they should exhibit significantly different performance even at long RTs. The alternative hypothesis, however, is supported by the data. As can be seen in FIGURE X, high spans reach their asymptotic level of performance before low spans. In other words, their attentional spotlight has contracted to its optimal size faster than low spans. To support this statistically, we considered the bins where

performance begins to rise from chance. Submitting the data from bins 4 through 10 to a repeated measures ANOVA revealed a significant span x latency bin quadratic interaction, as expected. A second, alternative way to test whether or not high spans achieve their asymptotic level of performance before low spans is to test each bin, beginning with the slowest bin (bin 10), against subsequent bins. The point at which a bin is significantly different from the preceding bin is the point at which performance reaches asymptote. For high spans, this is bin 7; for low spans, bin 9.

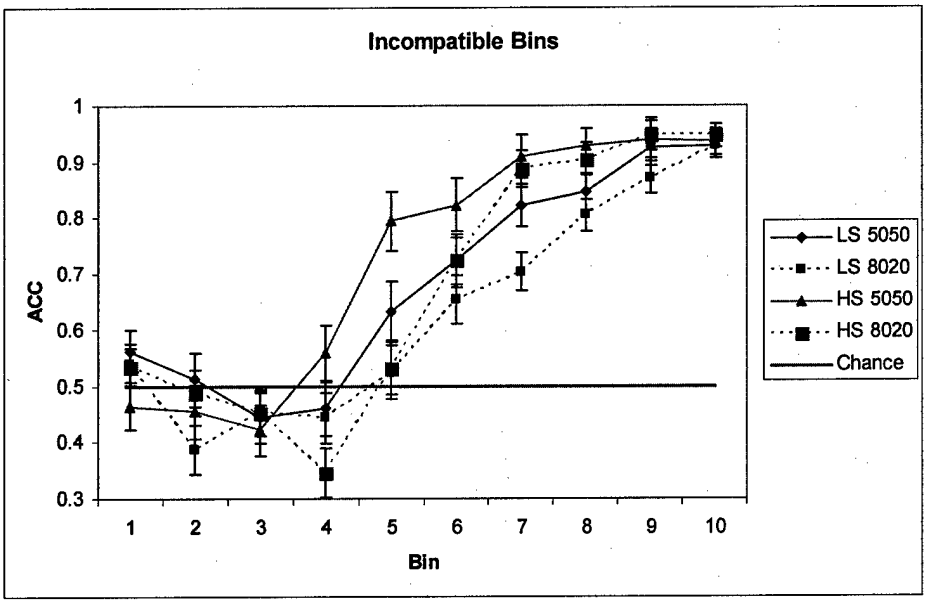
In a second experiment, we sought both to replicate the pattern of results just described and to examine what effect a manipulation of proportion compatibility would have. Kane & Engle (2003) found that in a Stroop task, increasing the proportion of compatible trials to incompatible trials results in increased goal neglect for low spans. In other words, when the goal of the task is not continually reinforced by incompatible trials, low spans are more likely to respond automatically. In terms of the Eriksen flanker task, we expected that a similar manipulation would increase difficulty, particularly for low span subjects. To this end, 80% of the trials were compatible, 20% incompatible. Nineteen low spans and twenty high spans participated.

As evident in FIGURE X, the same pattern of results emerged: chance level performance at fast RTs, below chance performance at a bit longer RTs, and asymptotic performance at long RTs. Again highs and lows did not differ in accuracy at the longest latencies (bin 10). Again, rate differences were evident. Considering bins 5 through 10, we found a significant span x latency bin linear interaction. In testing the bins individually, as before, we found that high spans reached their asymptote at bin 8; low spans at bin 10. It appears that the proportion

compatibility manipulation did not differentially affect highs and lows, but rather, increased difficulty for both groups.

In a final, third experiment, we set out to establish a boundary condition for this effect. Eriksen and his colleagues have determined that the lower limit on attentional constraint is approximately 1 degree of visual angle. The previous two studies employed an array size of approximately 2 degrees. We reasoned that if the previous effects were indeed due to attention, then using an array that is smaller than this lower limit should eliminate span differences. In essence, high spans may still be constraining their attentional spotlight faster than low spans, but this would not benefit them, because the entire array will still fall within the spotlight. That is, distractor letters could not be filtered out. Our subjects in experiment 3 (still ongoing) are presented with the 50/50 condition of Experiment 1, but now, the entire array spans .88 degrees of visual angle, with any one letter spanning approximately .22 degrees. Our preliminary results suggest that, as expected, span differences are eliminated when the array is so small that attention cannot possibly constrain around the single target letter.

Our Rate of Attention Constraint (RAC) model is a promising new avenue of research into how highs and lows differ in control of attention in the visual domain. But, more than this, it provides a new way of looking at the known correlation between speed of processing and individual differences in working memory capacity. Specifically, the speed-WMC relationship is incomplete in its present form; it requires an underlying mechanism to be meaningful rather than descriptive. That is, we need to answer the question "speed of what?" Although the task used to derive the RAC model is quite different from traditional speed of processing tasks, it may well turn out that "speed of attention" underlies the above said relationship.



Papers published under this grant:

1. Conway, A.R.A., Kane, M.J., & Engle, R.W. (2003). Working memory capacity and its relation to general intelligence. Trends in Cognitive Sciences, 7, 547-552

2. Mecklinger, A., Weber, K., Gunter, T.C., & Engle, R.W. (2003). Dissodciable brain mechanisms for inhibitory control: effects of interference content and working memory capacity. Cognitive Brain Research, 18, 26-39.

3. Bleckley, M. K., Durso, F. T., Crutchfield, J. M., Engle, R., & Khanna, M. (in press). Individual differences in working memory capacity predict visual attention allocation. Psychonomic Bulletin and Review.

4. Hambrick, D. Z., Kane, M. J., & Engle, R. W. (in press) The Role of Working Memory in Higher-Level Cognition: Domain-Specific vs. Domain-General Perspectives. In R. J. Sternberg & J. Pretz, Eds. Cognition and Intelligence, Cambridge University Press.

5. Engle, R.W. & Kane, M.J. (in press). Executive Attention, Working Memory Capacity, and a
Two-Factor Theory of Cognitive Control. In Ross, B. (Ed), The Psychology of Learning and Motivation, Vol 44. Academic Press:NY.

6. Feldman-Barrett, L., Tugade, M. & Engle, R.W. (in press). Dual process theories of mind. Psychological Bulletin.

7. Unsworth, N., Schrock, J. C., & Engle, R.W. (in press). Working Memory Capacity and the Antisaccade Task:: Individual Differences in Voluntary Saccade Control. Journal of Memory and Language.

8. Oberauer, K., Lange, E., & Engle, R.W. (in press) Working Memory Capacity and Resistance to Interference. Journal of Memory and Language.

9. Kane, M.J., Hambrick, D.Z., Tuholski, S.W., Wilhelm, O., Payne, T.W., Engle, R.W. (In Press) The Domain Generality of Working-Memory Capacity: A Latent-Variable Approach to Verbal and Visuo-Spatial Memory and Reasoning. Journal of Experimental Psychology: General.

10. Heitz, R.P., Unsworth, N. & Engle, R.W. (in press). Working memory capacity, attention, and fluid intelligence. In Wilhelm, O. & Engle, R.W. (Eds.), Handbook on Understanding and Measuring Intelligence, Sage Press: CA.

11. Unsworth, N., Heitz, R. P., & Engle, R.W. (in press). Working memory capacity and attention control. In Engle, R.W., Sedek, G., von Hecker, U. & McKintosh, D. (Eds.) Cognitive Limitations in Aging and Psychopathology: Attention, Working Memory, and Executive Functions. Cambridge University Press: London.

12. Wilhelm, O. & Engle, R.W. (Eds.). (in press). Handbook on Understanding and Measuring Intelligence, Sage Press: CA.

13. Engle, R.W., Sedek, G., von Hecker, U. & McIntosh, D. (Eds.). (in press.) Cognitive Limitations in Aging and Psychopathology: Attention, Working Memory, and Executive Functions. Cambridge University Press: London.