Journal of Experimental Psychology:
Learning, Memory, and Cognition
2008, Vol. 34, No. 3, 616–630

0278-7393/08/$12.00 DOI: 10.1037/0278-7393.34.3.616

Speed and Accuracy of Accessing Information in Working Memory: An Individual Differences Investigation of Focus Switching

Nash Unsworth
University of Georgia and Georgia Institute of Technology

Randall W. Engle
Georgia Institute of Technology

Three experiments examined the nature of individual differences in switching the focus of attention in working memory. Participants performed 3 versions of a continuous counting task that required successive updating and switching between counts. Across all 3 experiments, individual differences in working memory span and fluid intelligence were related to the accuracy of the counts, but not to the time cost associated with switching between counts. The authors suggest that working memory span and fluid intelligence measures partially index the ability to accurately switch information in and out of the focus of attention, but this variation is not related to the speed of switching.

Keywords: working memory, focus switching, individual differences

Working memory (WM) can be defined as a system responsible for the active maintenance, manipulation, and retrieval of task relevant information. Given these varied functions, it is not surprising that measures of WM have been found to be related to many higher-order cognitive functions, including reading comprehension and learning, and more broadly to fluid intelligence (see Engle & Kane, 2004). It is important, therefore, to examine aspects of each construct in detail and to examine the relations among these constructs to gain a better understanding of these important relations.

In the present article we explore aspects of a dynamic WM system that combines maintenance of information in the focus of attention with the retrieval of information from outside the focus. To place these two functions in a real-world context, consider the simple example of trying to multiply 2 two-digit numbers in your head (e.g., 47 × 23). To solve this problem, one must typically break the problem up into smaller problems, solve each of the smaller problems, and then combine the results. This process of breaking up the problem into more manageable subcomponents likely requires the use of efficient attention switching and updating mechanisms. The ability to quickly and accurately switch attention to recent representations is also likely required in other higher-order cognitive operations, including reasoning and language comprehension.

Speed and Accuracy of Accessing Recent Information

Several prominent models of memory have suggested that memory can be conceived as a hierarchical system of activated long-term memory units (Anderson, 1983; Atkinson & Shiffrin, 1968; Cowan, 1988). For instance, Cowan's (1988, 1995) model postulates a unitary memory system with three separate levels of activation. These differing levels of activation include long-term memory units that are currently inactive, long-term memory units that are active above some ambient activation level, and memory units that are highly active and are in the current focus of attention. Furthermore, Cowan's model suggests that a central executive mechanism biases or controls the focus of attention during voluntary processing, but that the focus can also be biased or controlled by habitual or involuntary processing. In this model, WM can be considered as both the active units inside and outside of the focus of attention and the central executive component.

Assuming that the focus of attention is limited in capacity and can hold only a small subset of currently relevant information (Cowan, 2001), whenever other relevant information needs to be processed, information in the focus of attention will have to be displaced from the focus and the new information will have to be retrieved back into the focus. As noted in the example above, this process of rapidly shunting information into and out of the focus of attention is likely needed in many cognitive operations. It is important that this process must be both fast and accurate in terms of accessing recently presented task-relevant information.

Given the importance of this process of switching information into and out of the focus of attention, recent research has been devoted to examining aspects of this process in dynamic memory updating tasks. For instance, Garavan (1998; see also Garavan, Ross, & Stein, 2000) used a continuous counting paradigm to examine attention switching in WM. In this task, participants were presented with either a rectangle or a triangle onscreen. The participant's task was to count the number of rectangles and triangles. The presentation of each figure was self-paced and the participants simply pressed the spacebar to advance. Within a sequence of trials, the current stimulus could either be the same as the previous stimulus (nonswitch) or could be different (switch). Thus, a participant could be presented with a triangle, followed by another triangle (nonswitch), a rectangle (switch), and finally another triangle (switch). After a variable number of geometric

Nash Unsworth, Department of Psychology, University of Georgia, and School of Psychology, Georgia Institute of Technology; Randall W. Engle, School of Psychology, Georgia Institute of Technology.

We thank Rich Heitz, Tom Redick, and Jim Broadway for helpful comments in all phases of this research project.

Correspondence concerning this article should be addressed to Nash Unsworth, who is now at the Department of Psychology, University of Georgia, Athens, GA 30602-3013. E-mail: nunswor@uga.edu

figures were presented, the participants were asked to recall how many of each figure they saw (e.g., three triangles and one rectangle). Of interest was the response-time difference between switch and nonswitch trials. Garavan reasoned that if participants could simultaneously hold and update two counters in memory, then there should be no difference between switch and nonswitch trials. However, if participants could only hold one counter in the focus at once, then the focus would have to be switched to update the new counter when participants were presented with a new figure. The results supported the latter hypothesis. Specifically, participants were approximately 300–500 ms slower on switch trials than nonswitch trials. This suggested that the capacity of the focus of attention encapsulates one item in this task, and thus items outside of the focus must be switched back into the focus for further processing.

Additional evidence for this assertion comes from several studies by Oberauer (2002, 2003) using another memory updating task. Relying mainly on response-time analyses, Oberauer found additional evidence for a time cost for retrieving items into the focus of attention as well as evidence that this switch cost is moderated by the number of relevant items that are outside of the focus of attention. That is, Oberauer found that as the set size of possible items increased, so did the magnitude of the switch cost. Oberauer (2002) suggested that this time cost reflected the time needed to select a given item from among several competitors; as the number of competitors increased, so did the time needed to retrieve that item back into the focus of attention. Furthermore, Oberauer (2003) found a slight increase in response times (RTs) as the lag increased for items outside of the focus of attention, suggesting that the longer an item had been out of the focus, the longer it took to retrieve it back into the focus. Collectively, these results suggest that information within the focus of attention is highly accessible for cognitive operations and that information outside of the focus must be retrieved back into the focus for further processing. Furthermore, this switching and retrieval mechanism takes time.

McElree (1998, 2001, 2006) has also emphasized a distinction between information within the focus of attention and information outside of the focus of attention, relying on time-course analyses in a number of paradigms. However, unlike the above research (which relied primarily on RT), McElree has also emphasized the importance of differences in accuracy measures of information inside and outside of the focus. McElree (2001) suggested that retrieval speed provides an index of the accessibility of an item, whereas accuracy reflects the availability of an item. Specifically, McElree has suggested that there are two functional states of accessibility: one associated with items in the focus of attention and one associated with all other items outside of the focus. Unlike Oberauer's (2003) findings on the effects of lag, suggesting an increase in RT as lag increased, McElree (2001) suggested that the time to access items with lag greater than zero is the same. Furthermore, McElree suggested that items within the focus are available for processing and thus are associated with a high accuracy rate. Items outside of the focus, however, demonstrate a monotonic decrease in availability due to decay or interference from other items. Thus, McElree's work suggests that not only is there a distinction between items inside and outside of the focus but also a distinction between the speed of retrieval and the accuracy of retrieval. Both of these distinctions need to be taken into account when examining the process of shifting information in and out of the focus of attention.

Verhaeghen and colleagues (Verhaeghen & Basak, 2005; Verhaeghen & Hoyer, 2007) have continued with this theme, demonstrating an age dissociation between the time needed to switch the focus of attention and the accuracy of the switching operation. Specifically, using a version of the *n*-back task, Verhaeghen and Basak (2005) found that older and younger adults did not differ in the time cost associated with switching the focus of attention; however, older adults were more error prone when switching the focus than younger adults were. Similarly, Verhaeghen and Hoyer (2007) found an age difference in accuracy and not in RT when switching the focus was needed in a continuous calculation task. Thus, like McElree's (2006) work, this suggests a distinction between the speed of retrieval associated with items outside of the focus of attention and the probability of correctly selecting a given item outside of the focus, with age differences occurring only for the latter.

Verhaeghen and colleagues (e.g., Verhaeghen & Hoyer, 2007) have also suggested that the process of switching the focus of attention is distinct from other putative executive functions such as task switching (Rogers & Monsell, 1995). Specifically, Verhaeghen and colleagues have suggested that focus switching involves switching items in and out of the focus of attention, whereas task switching involves performing different operations on items already in the focus. Thus, although both involve some type of switching, what exactly is switched is different between the two. It is possible, therefore, that either there is a general switching ability that cuts across different switching functions, or these two types of switching reflect different functions. Verhaeghen and Hoyer (2007) have recently suggested that focus switching and task switching represent distinct abilities that may individually be important for higher-order cognitive abilities. However, more work is needed to examine this claim more thoroughly. Overall, then, Verhaeghen and colleagues have suggested that focus switching is an important cognitive control function that may be important for performance in a number of cognitive tasks.

Focus Switching in WM Span Tasks

Given the need to quickly and accurately shunt information in and out of the focus of attention, it is likely that the ability to use this focus-switching mechanism determines performance in many tasks. For instance, this focus-switching mechanism would certainly play some role in immediate memory paradigms, as they require maintenance of information as well as rapid updating of items in the focus of attention. This ability to shift the focus of attention to items in memory is one likely variable that is important for performance on WM span tasks. For example, consider one common WM span task, the operation span task. Here, participants solve a math operation and then are presented with a to-be-remembered (TBR) item followed by another math operation–word string. The TBR item is held in the focus, but is quickly displaced because of the need to process the next operation. When the next TBR item is presented, it may be important to quickly switch the focus back to items that have been displaced to reactivate them. The more efficiently participants can switch the focus of attention and update the contents of active memory, the more likely they are to recall more items during the recall period.

This suggests that one reason some individuals (*high spans*) score high on these span tasks is because they can more rapidly and efficiently switch the focus of attention between items in memory (see Towse, Hitch, & Hutton, 2000, for a related view) than individuals who score low on these tasks (*low spans*). That is, high spans may be better at shunting information in and out of the focus than low spans, which then enables them to recall more items later on. In line with the work of McElree (2001) and Verhaeghen and colleagues (Verhaeghen & Basak, 2005; Verhaeghen & Hoyer, 2007) discussed above, there are two main factors that could differentially affect high and low spans: the speed of retrieving information outside of the focus and the accuracy of retrieving information outside of the focus. Figure 1 shows a schematic depiction of recent information inside and outside of the focus of attention, based on the views discussed previously. Here it is assumed that the focus of attention encapsulates only one item; thus, if other information needs to be in the focus for further processing, a switch must occur (e.g., McElree, 2001; Oberauer, 2002).

In terms of possible differences in WM span, it is possible that high spans are faster at retrieving items that have been recently displaced from the focus than low spans and thus are better able to reactivate those items before they decay or are subjected to retroactive interference. Within the framework depicted in Figure 1, this suggests that high spans are faster at replacing X_j in the inside of the focus with X_i on the outside of the focus. This process would likely entail disengaging attention from the current contents of the focus and reactivating the correct item on the outside of the focus, all of which takes time. If this process is not done rapidly, it is possible that information on the outside of the focus will be lost rapidly due to decay or retroactive interference.

Conversely, it is possible that high and low spans do not differ in the speed at which they can shunt information in and out of the focus of attention, but rather high spans are better able to retrieve the correct item (X_i) from outside of the focus among many competing items (the *I*s). Thus, in the current framework this would mean that high spans are better at retrieving relevant information on the outside of the focus than low spans (e.g., Unsworth & Engle, 2007). Clearly, then, this would entail an accurate discrimination process that would discriminate between relevant and irrelevant information, allowing for correct retrieval. Any noise in such a process would lead to inaccurate recalls. In terms of WM span differences, this would result in high spans recalling more correct items than low spans, due to their ability to correctly retrieve relevant information in the presence of irrelevant information. This possibility is consistent with the findings of Verhaeghen and colleagues (Verhaeghen & Basak, 2005; Verhaeghen & Hoyer, 2007) in terms of age differences in focus switching. As noted above, in those studies older and younger adults did not differ in the speed of retrieving information outside of the focus but did differ in the accuracy of those retrievals, with younger adults being more accurate than older adults. Finally, it is possible for high and low spans to differ in both the speed and accuracy of the focus-switching processes, which then leads to differences in recall abilities seen in tasks like the WM span tasks.

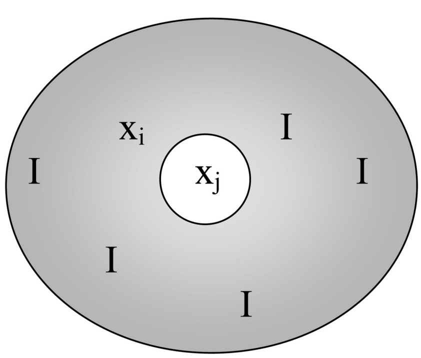

Figure 1. Schematic depiction of recent information inside and outside of the focus of attention. Assuming a subset of relevant information (the center, X_j) is maintained in the focus (here one item), other relevant information (X_i, outside the focus) must be retrieved among other recently presented information that is now irrelevant (the *I*s).

Furthermore, it is possible that one reason performance on these WM span tasks correlates so well with performance on other cognitive tasks (see above) is because of limitations in the focus-switching process that is needed in many cognitive tasks. Like the possibilities discussed above, working spans may correlate well with other measures because of individual differences in the speed of retrieval, the accuracy of retrieval, or some combination of both speed and accuracy.

Present Study

In the present study we attempted to determine the role of focus switching in working memory capacity (WMC) and fluid abilities. To examine this, we asked participants to perform a version of Garavan's (1998) continuous counting task. In this task, participants were required to count different objects presented alone (e.g., big or small squares) and keep a running count of each type of object. Consistent with Garavan, our idea was that in some situations the size of the focus of attention encapsulates only one item (count), and thus attentional switches must be made from count to count. After a variable number of objects had been presented, participants were required to report their counts for each object separately.

Within the current framework and this particular task, there are two main things to measure and be concerned with. The first is the time cost incurred by switching from one object to another during counting (e.g., counting big squares and then counting small squares). Consistent with Garavan (1998), RTs should increase when switching to a new object compared to updating the same object consecutively. In line with Oberauer (2002), this time cost is referred to as an *object switching cost;* it is considered an index of the speed of retrieval involved in focus switching. The second concern is the accuracy of the resulting counts. Presumably, the accuracy of the counts provides an index of the accuracy of the mechanism for retrieving the correct item and is thus an index of the availability of items outside of the focus of attention. With these two measures in mind, one of the main questions addressed in the current article concerns the role of WMC in focus switching. Specifically, is WMC (as measured by complex WM span tasks) related to the speed of the focus-switching operation, the accuracy of the focus-switching operation, or both? As noted earlier, there are arguments for all three possibilities.

An additional main question concerns the role of *fluid abilities* (gF) in focus switching. Specifically, is gF (as measured by

Ravens) related to attention switching, updating and retrieval, or both? Additional questions are concerned with what factors affect focus switching. Specifically, the current study examined how the frequency of switches required (Experiments 1–3), the number of counts that must be switched between (Experiment 2), and the type of operations performed on the counts (Experiment 3) would affect both the speed and accuracy of the focus-switching operation and its relation to both WMC and gF.

Experiment 1

In Experiment 1, high and low span participants performed a version of Garavan's (1998) counting task. Participants counted big and small squares at their own pace. Upon presentation of an object, participants pressed the spacebar to move on to the next object. The time taken to press the spacebar when objects switched versus when objects repeated provided the object switching cost. After a variable number of objects were presented, participants typed in the count for big squares followed by the count for small squares.

We also manipulated the frequency of switches (low, medium, and high) to determine the efficiency of focus switching. It is possible that it would take longer to direct the focus with more switches than with relatively few switches (e.g., Garavan et al., 2000). Furthermore, WM span differences may emerge when many switches are required, resulting in some representations being retrieved from outside the focus of attention among other competing representations. That is, with few switches it is possible that low and high spans may not differ in either speed or accuracy of focus switching; but as more switches are required, differences will begin to appear as the efficiency of the switching processes breaks down. Our aim was to better understand the dynamics of the focus of attention and individual differences therein.

Participant Screening for WM Span and Raven Progressive Matrices

Participants were prescreened for WMC using the operation span task (Ospan; Turner & Engle, 1989). The Ospan has demonstrated good reliability and validity (Conway et al., 2005; Klein & Fiss, 1999; Engle, Tuholski, Laughlin, & Conway, 1999). The task requires participants to solve a series of math operations while trying to remember a set of unrelated words. For example, participants may see *Is (9/3) – 1 = 1? Dog.* The participant is required to read the operation aloud without pausing and then to verify aloud whether the operation is correct ("yes" vs. "no"). After verification, participants are required to read the word aloud, again without pausing. Once the participant reads the word aloud, the experimenter presses a key to move on to the next operation–word string. The same procedure is repeated until three question marks (*???*) appear, indicating to the participant that it is time to recall the words from that set in the correct order. The operation–word strings vary from two to five items in length. The Ospan score is the sum of recalled words for all perfectly recalled sets. In the present study, three sets of each length (two to five operation–word pairs) were presented to each participant, with possible scores ranging from 0 to 42. Additionally, to ensure that participants were not trading off between solving the operations and remembering the words, an 85% accuracy criterion on the math operations was required for all participants.

In addition to completing the Ospan, participants also completed a version of Raven's Progressive Matrices (Raven et al., 1998). The Raven is a measure of abstract reasoning. This version of the Raven is computer administered and consists of 36 individual items presented in three segments of 12 items each. Within each segment, the items are presented in ascending order of difficulty (i.e., the easiest item is presented first and the hardest item is presented last). Each item consists of a matrix of geometric patterns with the bottom right pattern missing. The task for the participants was to select from either six or eight alternatives the one that correctly completed the overall series of patterns. Each matrix item appeared separately on screen along with the response alternatives. Using the mouse, the participants simply clicked on the response that they thought completed the pattern. The mouse click registered the response and moved the program on to the next problem. Participants were allotted 5 min to complete each segment. Thus, the task lasted for either 15 min or as long as it took to solve all 36 problems. A participant's score was the total number of correct solutions. Participants received two practice problems.

Method

Participants and design. Participants were 28 high spans and 26 low spans, as determined by the Ospan. Those participants were classified on the basis of a distribution of over 2,000 Ospan scores from our laboratory, with high spans falling in the upper quartile of the distribution and low spans falling in the lower quartile. Participants were recruited from the subject pool at Georgia Institute of Technology and from the Atlanta community through newspaper advertisements. They were between the ages of 18 and 35 and received either course credit or monetary compensation for their participation. Each participant was tested individually in a laboratory session lasting approximately 45 min. The design was a 2 (span: high vs. low) × 3 (frequency: high, medium, low) × 2 (switch: switch vs. nonswitch) mixed factorial design, with frequency and switch as the within-subjects variables.

Procedure. After signing informed consent, participants were provided with instructions on the task procedure. Each trial began with the participant being presented with a fixation point on screen for 150, 300, or 600 ms (which was random for each trial), followed by either a big or a small square. The participant's task was to keep a running count of the number of big and small squares they saw. With the presentation of a square, the participant added the square to the current count and rehearsed the other count (Garavan et al., 2000). For example, if a participant had already seen three big squares and three small squares and was then presented with a big square, the participant would say "four big and three small." Rehearsal could be either covert or overt. Garavan (1998) found that nearly all participants adopted this scheme while counting. The participant would then press the space bar; the fixation point would again appear, followed by a new square. The space bar registered the time it took to update the current count in milliseconds. Participants were instructed to be as fast and accurate as possible while counting. At the end of each trial, a screen appeared asking the participant how many big squares they saw, followed by a screen asking how many small squares they saw. Here, the accuracy of the counts was recorded.

The task consisted of 5 practice trials and 45 real trials. A trial consisted of 11–15 squares (585 total) and the two accuracy screens. In total, there were 420 nonswitch subtrials and 165 switch subtrials. Additionally, there were 15 trials for each of the three frequency conditions (high, medium, and low). Low-frequency trials consisted of only one 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 one switch; on medium-frequency trials, 25% of the trials required a switch; and on high-frequency trials, 50% of the trials required a switch (e.g., Garavan et al., 2000). The different frequency trials were randomly interleaved.

Results

Participants. Data for one low span participant were excluded from data analyses due to low accuracy rates on both counts (i.e., less than 50% on both counts). The mean Ospan scores for the final 28 high spans and 25 low spans were 25.14 ($SD = 5.54$, range = 19–37) and 6.6 ($SD = 2.53$, range = 0–9), respectively. The mean ages for the high and low span participants were 21.46 (SD = 3.93) and 23.96 ($SD = 4.72$), respectively.

Accuracy. Accuracy of the counts for big and small squares was examined first. The results suggest that overall accuracy was high ($M = 0.91$, $SE = 0.01$), but the count for big squares was slightly more accurate than the count for small squares ($M = 0.92$, $SE = 0.01$ vs. $M = 0.90$, $SE = 0.01$). The results also suggest that the frequency of switches negatively impacted the accuracy of the counts, with low frequency switch trials being the most accurate ($M = 0.93$, $SE = 0.01$) and accuracy rate decreasing for medium frequency switch trials ($M = 0.91$, $SE = 0.02$) and high frequency switch trials ($M = 0.90$, $SE = 0.02$). High span participants were also more accurate than low span participants ($M = 0.94$, SE = 0.02 vs. $M = 0.89$, $SE = 0.02$). As shown in Figure 2, this difference was moderated by the frequency of switches on a given trial, with the smallest span difference occurring for low frequency switch trials and the differences increasing for medium frequency switch trials and high frequency switch trials. In fact, as shown in Figure 2, low span individuals' accuracy rate decreased markedly as frequency increased, but high span individuals' accuracy remained relatively unchanged as frequency increased.

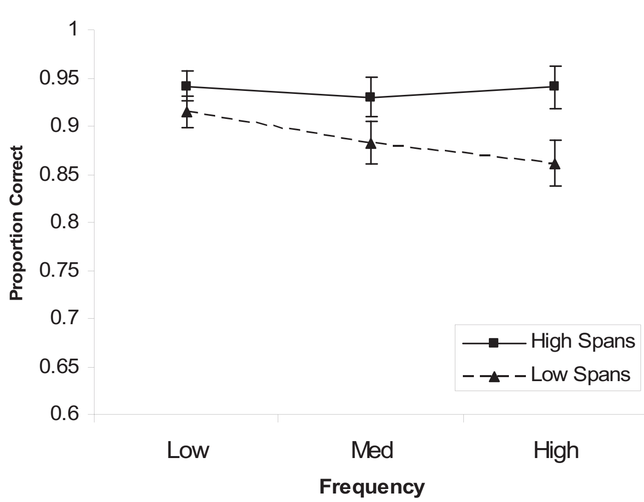

Figure 2. Total proportion correct as a function of switching frequency and working memory span. Error bars represent one standard error of the mean. Med = medium.

These observations were supported by a 2 (span: high vs. low) × 2 (object: big vs. small) × 3 (frequency: low, medium, high) mixed analysis of variance (ANOVA), with object and frequency as the within-subjects factors. The ANOVA demonstrated main effects of object, $F(1, 51) = 9.36$, $MSE = 0.005$, $p < .01$, partial $\eta^2 = .16$, and span, $F(1, 51) = 4.36$, $MSE = 0.05$, $p < .05$, partial $\eta^2 = .08$. Neither the object by span interaction nor the three-way interaction involving span, object, and frequency was significant, both ps > .22. There was also a linear main effect of frequency, indicating that accuracy decreased as frequency increased, $F(1, 51) = 3.64$, $MSE = 0.01$, $p = .05$, partial $\eta^2 = .07$. Finally, as shown in Figure 2, the linear span by frequency interaction approached conventional levels of significance, $F(1, 51) = 3.61$, $MSE = 0.01$, $p = .06$, partial $\eta^2 = .07$. Examining the frequency effect separately for high and low span participants suggested that the effect of frequency was significant for low spans, $F(2, 48) = 3.47$, $MSE = 0.01$, $p < .05$, partial $\eta^2 = .13$, but not for high spans, $F(2, 54) = 0.38$, $MSE = 0.003$, $p > .68$, partial $\eta^2 = .01$.

Further examination of the participants' incorrect counts suggested that the majority of the counts were under the correct value (68.5%) and the majority of the counts were within ±1 of the correct value (73.9%). Furthermore, this did not seem to differ as a function of span, with the majority of both high and low span participants' counts being under the correct value (72.2% vs. 64.7%) and the majority of high and low span participants' counts being within ±1 of the correct value (75.6% vs. 72.1%). Thus, although low spans were more likely than high spans to be incorrect in their counts, both high and low spans tended to be under the correct value by one.

Response time. An examination of RTs suggested that responses were slower on switch trials than on nonswitch trials (overall switch cost = 514 ms), and responses slowed as a function of the number of switches required on a trial. That is, participants were fastest on low switch trials (1,056 ms), followed by medium switch trials (1,178 ms), and finally high switch trials (1,199 ms). Furthermore, the frequency of switches required on a trial impacted the magnitude of the switch cost such that switch costs were smallest on high frequency switch trials (switch cost = 376 ms), compared to either low frequency switch trials (switch cost = 555 ms) or medium frequency switch trials (switch cost = 610 ms). Finally, the results suggested that the only effect of WM span was a slight difference between high and low span individuals on RT for high frequency switch trials and no differences in RT on either low or medium frequency switch trials, and no differences in switch costs (high switch cost = 524 ms vs. low switch cost = 504 ms). Thus, although there were prominent effects of frequency and switches on RT, high and low span individuals tended to have fairly similar RTs.

These conclusions were supported by a 2 (span: high vs. low) × 2 (switch: switch vs. nonswitch) × 3 (frequency: low, medium, high) mixed ANOVA, with switch and frequency as the within-subjects factors. The ANOVA demonstrated a main effect of switch, $F(1, 51) = 225.01$, $MSE = 93{,}003$, $p < .01$, partial $\eta^2 = .82$, but a nonsignificant main effect of span, $F(1, 51) < 1$. There was also a main effect of frequency indicating that RT increased as frequency increased, $F(2, 102) = 37.97$, $MSE = 16{,}652$, $p < .01$, partial $\eta^2 = .42$. The ANOVA also demonstrated a significant Frequency × Switch interaction, $F(2, 102) = 30.61$, $MSE = 12{,}921$, $p < .01$, partial $\eta^2 = .38$, and a Frequency × Span interaction, $F(2, 102) = 3.38$, $MSE = 16{,}652$, $p < .05$, partial $\eta^2 = .06$. Neither the Switch × Span, $F(1, 51) < 1$, nor the Frequency × Switch × Span, $F(2, 102) = 1.10$, $MSE = 12{,}921$, $p > .33$, partial $\eta^2 = .02$, was significant.

Lags and runs. In addition to examining overall mean RT, we also examined RT as a function of lags and runs. That is, we examined how RT would change as a function of the number of times the same count was updated before a switch occurred (runs) as well as the amount of time since its last update that passed before a count was updated (lags). Note that lags and runs are not necessarily the same; many runs could occur before a switch ever occurred (especially in the low switch frequency condition), whereas lags could only be computed after at least one switch occurred.

First we examined lag effects. There were five levels of lag. The first level was Lag 0, where the same count was updated in succession (i.e., a run of at least 1). The other four lags consisted of a switch trial where the current count was updated after 1, 2, 3, or 4 updates of the other count. That is, on Lag 2, the current count was updated after the other count had been updated twice immediately before the current count. The resulting lag functions are shown in Figure 3A collapsed on frequency condition. As can be seen, RTs were fastest on Lag 0 and then increased for the other lags (the switch cost).

These observations were supported by a 2 (span: high vs. low) × 5 (lag: 0, 1, 2, 3, 4) mixed ANOVA, with lag as the within-subjects factor. The only significant effect was a main effect of lag, $F(4, 204) = 101.42$, $MSE = 68{,}962$, $p < .01$, partial $\eta^2 = .67$, suggesting that RT increased as lag increased. Neither the main effect of span nor the Span × Lag interaction were significant, both *F*s < 1.

An analysis of run effects demonstrated largely similar results. Shown in Figure 3B are the run functions collapsed on frequency. As can be seen, a run of zero (a switch trial) was associated with the slowest RTs, and then RTs tended to speed up as run increased, up to a run of five or more, suggesting that participants were benefiting from stimulus repetition effects. Note that because there were so few trials at runs of five, six, and seven, we averaged those three runs together. Additionally note that a slight increase in RT was associated with a run of five or more. This increase likely represents anticipatory effects where participants slowed down in anticipation of a switch trial. Furthermore, note that these run effects partly explain why switch costs are so large in the low frequency switch condition. Specifically, there are long runs in the low frequency switch condition, allowing participants to get faster during the trial and leading to inflated switch costs when switch does occur. As with lag effects, the effects of runs did not interact with WM span.

These observations were supported by a 2 (span: high vs. low) × 6 (run: 0, 1, 2, 3, 4, 5+) mixed ANOVA, with run as the within-subjects factor. As with the lag analyses, the only significant effect was a main effect of run, $F(5, 255) = 209.03$, $MSE = 19{,}008$, $p < .01$, partial $\eta^2 = .80$, suggesting that RTs generally decreased as run increased. *F* values for both the main effect of span and the Span × Run interaction were less than one.

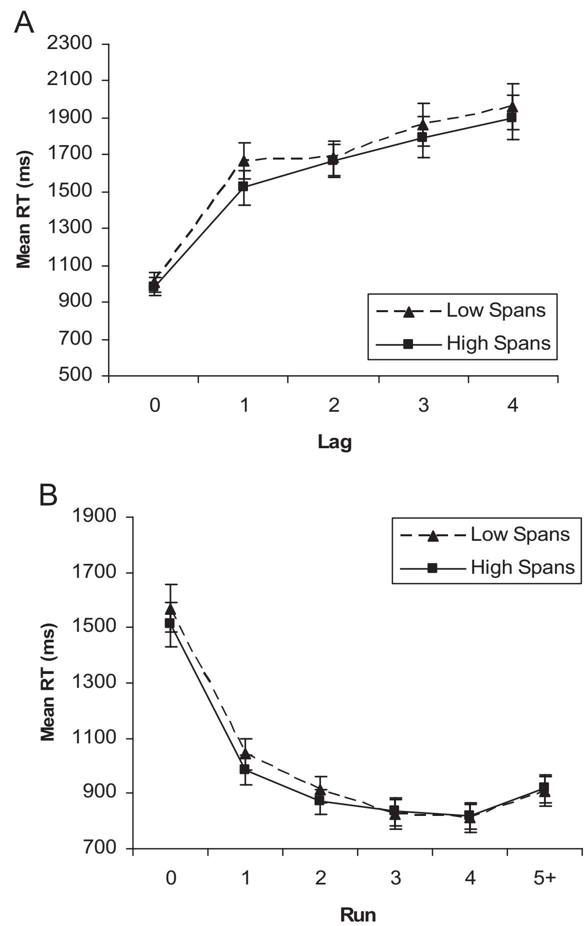

Figure 3. A: Response time (RT) as a function of lag since the last switch and working memory span. B: RT as a function of the number of runs before a switch and working memory span. Error bars represent one standard error of the mean.

Correlations. To examine the differential predictive utility of the speed and accuracy components, we analyzed the correlations between switch costs, accuracy of the counts, and performance on one measure of gF (i.e., Raven). The first correlation analysis examined the extent to which mean accuracy and mean switch costs were related to one another and related to performance on Raven. With 52 participants, the correlations suggested that mean accuracy on the counts was significantly related to performance on Raven ($r = .27$, $p = .05$), but that mean switch costs were not related to performance on the Raven ($r = -.07$, $p > .63$), nor were they related to accuracy of the counts ($r = .03$, $p > .82$). Note that the correlations are based on only 52 participants because the Raven score for one low span participant was unavailable.

To examine these correlations more clearly, we analyzed the correlations between switch costs, accuracy of the counts, and performance on Raven as a function of the frequency of switches required on a trial. The resulting correlations are shown in Table 1.

Table 1
Experiment 1: Correlations for Accuracy and Switch Costs in the Counting Task With Raven

Variable	1	2	3	4	5	6	7
1. Raven	—						
2. LFacc	.32*	—					
3. MFacc	.35*	.62**	—				
4. HFacc	.43**	.55**	.73**	—			
5. LFcost	−.05	−.01	−.07	.09	—		
6. MFcost	−.08	.06	−.02	−.02	.80**	—	
7. HFcost	−.05	.05	.04	−.05	.55**	.79**	—

Note. LF = low frequency switch trial; acc = accuracy; MF = medium frequency switch trial; HF = high frequency switch trial; cost = switch costs.
* $p < .05$. ** $p < .01$.

The correlations suggest several interesting things. First, accuracy at all levels of frequency is highly correlated with one another. Second, switch costs at all levels of frequency are highly correlated with one another. Third, accuracy of the counts and switch costs are not correlated with one another. Fourth, only accuracy is significantly correlated with scores on the Raven. These results suggest that, at least within the current task, the accuracy of focus switching is related to gF, but the speed of focus switching is not.

Discussion

The results for Experiment 1 were rather straightforward. In terms of accuracy, low span participants were more inaccurate in their counts than high span participants; increasing the number of switches that were required on a trial decreased accuracy for low span participants but had no effect on high span participants. Furthermore, regardless of span, when an incorrect count was given, the count tended to be within 1 of the correct count. In terms of speed of counting, switch trials were much slower than non-switch trials, and this changed as a function of the frequency of switches on the trial. However, high and low span participants did not differ in either their overall RTs or in their switch costs. Additionally, the lag analyses suggested that the further back in time a count was last updated, the longer it took to update the count. This was partially because participants got faster as runs increased.

The correlation analyses suggest that speed and accuracy were not correlated in this task and that performance on the Raven was correlated only with the accuracy of the counts and not the time associated with switching counts. At no point did the switch costs correlate with performance on the Raven. It is important to point out that switch costs associated with the three levels of frequency were highly correlated with one another; thus, the lack of a correlation between switch costs and scores on Raven was not due to a lack of systematic variance in the switch costs. Collectively these results suggest that the speed of focus switching is not related to either WM span or performance on Raven, but the accuracy of the focus-switching mechanism is. That is, high and low span individuals do not seem to differ in the speed with which they switch the focus of attention to relevant information outside of the focus, but they do differ in the probability that they will switch to the correct information.

Experiment 2

In Experiment 2 we sought to replicate and extend the basic findings of Experiment 1. Specifically, we were interested in whether the number of counts that participants have to switch between would affect both the speed and the accuracy of switching and whether this would be differentially related to WMC and gF. In Experiment 1 participants attempted to keep two running counts of objects, whereas in this experiment participants were required to keep three running counts. We thought that this would make the task slightly more difficult than Experiment 1, thereby increasing possible span differences and providing information about focus-switching operations in a more complex task environment. To examine this, we asked high and low span participants to perform a version of Garavan's (1998) counting task in which they counted squares, circles, and triangles as accurately as possible and at their own pace (see also Li et al., 2004). As with Experiment 1, frequency of switches was manipulated (medium vs. high) to examine the efficiency of the switching operation.

Participant Screening for WM Span and Raven Progressive Matrices

Participants were prescreened for WMC using an automated version of the Ospan (Turner & Engle, 1989; Unsworth, Heitz, Schrock, & Engle, 2005). As with the original Ospan task, the automated version requires participants to solve a series of math operations while trying to remember a set of unrelated items. Specifically, participants solved a series of math operations while trying to remember a set of unrelated letters (*F, H, J, K, L, N, P, Q, R, S, T,* and *Y*). Participants were required to solve a math operation; after solving it, they were presented with a letter for 1 s. Immediately after the letter was presented, the next operation was presented. Three trials of each list length (three to seven items) were presented, with the order of list length varying randomly. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters (see Unsworth et al., 2005, for more details). Participants received three practice sets (of list length two). For all of the span measures, items were scored if the item was correct and in the correct position. The Ospan score is the sum of recalled words for all perfectly recalled sets (maximum score = 75). Additionally, to ensure that participants were not trading off between solving the operations and remembering the words, an 85% accuracy criterion on the math operations was required for all participants.

As in Experiment 1, participants completed a version of the Raven Progressive Matrices (Raven et al., 1998). This version of the Raven was the same as that used in Experiment 1, but here only one segment of 12 items was used. Participants had 5 min to solve as many of the 12 problems as possible. A participant's score was the total number of correct solutions. Participants received two practice problems.

Method

Participants and design. Participants were 31 high spans and 28 low spans, as determined by the automated version of the Ospan. Participants were recruited from the subject pool at Georgia Institute of Technology and from the Atlanta community through newspaper advertisements. They were between the ages of 18 and 35 and received either course credit or monetary compensation for their participation. Each participant was tested individually in a laboratory session lasting approximately 45 min. The design was a 2 (span: high vs. low) × 2 (frequency: high and medium) × 2 (switch: switch vs. nonswitch) × 3 (object: square, circle, triangle) mixed factorial design, with frequency, switch, and object as the within-subjects variables.

Procedure. After signing informed consent, participants were provided with instructions of the task procedure. Each trial began with the participant being presented with a fixation point on screen for 150, 300, or 600 ms, followed by one of the three objects. The participant's task was to keep running counts of the number of squares, circles, and triangles they saw. With the presentation of each object, the participant added the object to the current count and rehearsed the other counts. For example, if a participant had already seen three squares, two circles, and four triangles and was then presented with another square, the participant would say "four squares, two circles, and four triangles." The participant would then press the space bar; the fixation point would again appear and then a new object. The space bar registered the time it took to update the current count in milliseconds. Participants were instructed to be as fast and accurate as possible while counting. At the end of each trial a screen appeared asking the participants how many squares they saw, followed by a screen asking how many circles they saw, and finally another screen asking how many triangles they saw. Here, the accuracy of the counts was recorded.

The task consisted of 5 practice trials and 34 real trials. A trial consisted of 11–15 objects (452 total objects) and the three accuracy screens. In total, there were 279 nonswitch subtrials and 173 switch subtrials. Additionally, there were 17 trials for each of the two frequency conditions (high and medium).

Results

Participants. Data for four low span participants were excluded from data analyses due to low accuracy rates on both counts (i.e., less than 50% on both counts). The mean Ospan scores for the final 31 high and 24 low spans were 59.58 (SD = 7.11, range = 51–75) and 19.1 (SD = 6.36, range = 6–28), respectively.

Accuracy. Accuracy of the counts for all three objects was examined first. Overall accuracy levels were high (M = 0.90, SE = 0.01); the count for squares was the most accurate (M = 0.94, SE = 0.01), followed by the count for triangles (M = 0.91, SE = 0.02) and then circles (M = 0.87, SE = 0.01). Similar to Experiment 1, the results suggested that medium frequency switch trials were more accurate than high frequency switch trials (M = 0.93, SE = 0.01 vs. M = 0.87, SE = 0.01). Also, similar to Experiment 1, high span participants were more accurate than low span participants (M = 0.95, SE = 0.02 vs. M = 0.85, SE = 0.02). This difference was also moderated by the frequency of switches on a given trial, with span differences increasing as the frequency of switches required on a trial increased. Additionally, span differences in the accuracy of the counts interacted with both object and frequency such that span differences were the largest for the count of circles in the high frequency switch condition.

These initial observations were supported by a 2 (span: high vs. low) × 2 (frequency: medium and high) × 2 (object: square, circle, triangle) mixed ANOVA, with object and frequency as the within-subjects factors. The ANOVA demonstrated main effects of object, $F(2, 106) = 14.12$, $MSE = 0.01$, $p < .01$, partial $\eta^2 = .21$; frequency, $F(1, 53) = 47.46$, $MSE = 0.005$, $p < .01$, partial $\eta^2 = .47$; and span, $F(1, 53) = 18.23$, $MSE = 0.04$, $p < .01$, partial $\eta^2 = .26$. Additionally, the ANOVA demonstrated significant two-way interactions of Object × Span, $F(2, 106) = 19.43$, $MSE = 0.01$, $p < .01$, partial $\eta^2 = .27$; Span × Frequency, $F(1, 53) = 25.15$, $MSE = 0.005$, $p < .01$, partial $\eta^2 = .32$; and Object × Frequency, $F(2, 106) = 8.58$, $MSE = 0.005$, $p < .01$, partial $\eta^2 = .14$. Finally, as shown in Figure 4, all of these effects were qualified by a significant Object × Frequency × Span interaction, $F(2, 106) = 8.97$, $MSE = 0.005$, $p < .01$, partial $\eta^2 = .15$.

Follow-up analyses suggested that there was a marginal effect of frequency on accuracy for high spans, $F(1, 30) = 3.45$, $MSE = 0.003$, $p = .07$, partial $\eta^2 = .10$, but that neither the effect of object nor the Object × Frequency interaction were significant, both Fs < 1. For low spans, however, all effects were found to be significant. That is, examining only low span participants, there were main effects of object, $F(2, 46) = 20.62$, $MSE = 0.01$, $p < .01$, partial $\eta^2 = .47$, and frequency, $F(1, 23) = 40.70$, $MSE = 0.01$, $p < .01$, partial $\eta^2 = .64$, as well as a significant Object × Frequency interaction, $F(2, 46) = 10.16$, $MSE = 0.01$, $p < .01$, partial $\eta^2 = .31$. Thus, accuracy rates of low span participants—but not high span participants—changed as a function of both the sequence of objects being counted and the frequency of switches required on a particular trial, with accuracy being the worst for circles in the high frequency condition. This is possibly due to the fact that participants were instructed to rehearse the counts in the order of square, circle, triangle; thus, low spans, but not high spans, tended to focus most of their efforts on getting the first count right, to the detriment of the other two counts.

Further examination of participants' counts suggested that the counts were roughly equally likely to be both over and under the correct count, and the majority of the counts were within ±1 of the correct value (75.3%). Furthermore, this did not seem to differ as a function of span, with the majority of high and low span participants' counts being within ±1 of the correct value (69.6% vs. 80.1%). Thus, as in Experiment 1, low spans were less accurate in their counts than high spans, but when both highs and lows were incorrect, they tended to be off the correct value by ±1.

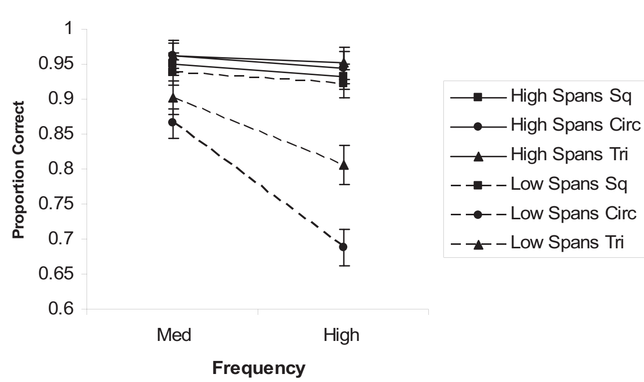

Figure 4. Proportion correct as a function of switching frequency, object, and working memory span. Error bars represent one standard error of the mean. Sq = square object; Circ = circle object; Tri = triangle object; Med = medium.

Response time. Similar to Experiment 1, an examination of RTs suggested that responses were slower on switch trials than on nonswitch trials (overall switch cost = 581 ms), and responses slowed as a function of the number of switches required on a trial, with participants responding faster on medium switch trials (1,694 ms) than high switch trials (1,794 ms). Additionally, as in Experiment 1, the results suggested a slightly larger difference between high and low span individuals on RT for high frequency switch trials than on medium frequency switch trials, and suggested no differences in switch costs (high switch cost = 555 ms vs. low switch cost = 608 ms). However, unlike Experiment 1, here low span individuals were much slower in responding overall (2,006 ms) than high span individuals (1,482 ms).

These conclusions were supported by a 2 (span: high vs. low) × 2 (switch: switch vs. nonswitch) × 2 (frequency: medium, high) mixed ANOVA, with switch and frequency as the within-subjects factors. The ANOVA demonstrated a main effect of switch, $F(1, 53) = 220.53$, $MSE = 18{,}300{,}904$, $p < .01$, partial $\eta^2 = .81$; a main effect of span, $F(1, 53) = 16.91$, $MSE = 14{,}872{,}495$, $p < .01$, partial $\eta^2 = .24$; and a main effect of frequency, $F(1, 53) = 30.08$, $MSE = 18{,}001$, $p < .01$, partial $\eta^2 = .36$. The only other effects to approach conventional levels of significance were the Span × Frequency interaction, $F(1, 53) = 3.23$, $MSE = 18{,}001$, $p = .08$, partial $\eta^2 = .06$, and the Span × Frequency × Switch interaction, $F(1, 53) = 2.99$, $MSE = 6{,}307$, $p = .09$, partial $\eta^2 = .05$.

Lags and runs. As with Experiment 1, lags and runs were also examined. Lag effects were examined first for seven levels of lag. The first level is Lag 0 where the same count was updated in succession (i.e., a run of at least 1). The other six lags consisted of a switch trial where the current count was updated after 2, 3, 4, 5, 6, or 7+ updates of the other count. There were no Lag 1 trials in the current experiment. The resulting lag functions are shown in Figure 5A collapsed on frequency condition. As can be seen, there was a large difference between Lag 0 RTs and RTs associated with all other lags (the switch cost), whereas differences in RTs for the other lags were slight.

These observations were supported by a 2 (span: high vs. low) × 7 (lag: 0, 2, 3, 4, 5, 6, 7+) mixed ANOVA, with lag as the within-subjects factor. There were significant main effects of lag, $F(6, 318) = 36.73$, $MSE = 170{,}929$, $p < .01$, partial $\eta^2 = .41$, and span, $F(1, 53) = 14.10$, $MSE = 490{,}027$, $p < .01$, partial $\eta^2 = .21$. The two-way interaction was not significant, $F < 1$.

As shown in Figure 5B, run effects were largely similar to Experiment 1. As with Experiment 1, a run of zero (a switch trial) was associated with the slowest RTs, and then RTs speeded up as run increased up to a run of three, suggesting that participants were benefiting from stimulus repetition effects. These observations were supported by a 2 (span: high vs. low) × 4 (run: 0, 1, 2, 3) mixed ANOVA, with run as the within-subjects factor. As with the lag analyses, there were main effects of run, $F(3, 159) = 67.49$, $MSE = 153{,}401$, $p < .01$, partial $\eta^2 = .56$, suggesting that RTs generally decreased as run increased; and span, $F(1, 53) = 25.87$, $MSE = 672{,}253$, $p < .01$, partial $\eta^2 = .33$. The two-way interaction was not significant, $F < 1$.

Correlations. As with Experiment 1, the differential predictive utility of the speed and accuracy components was analyzed by comparing the correlations between switch costs and accuracy of the counts to performance on the Raven. Note that Raven data were available for only 34 of the current participants, so the current results should be viewed with some caution. An examination of the correlation suggested that mean accuracy on the counts was significantly related to performance on the Raven ($r = .47$, $p < .01$), but once again mean switch costs were not significantly related to either performance on the Raven ($r = -.21$, $p > .24$) or to accuracy of the counts ($r = .18$, $p > .32$). As with Experiment 1, the correlations were further examined as a function of the frequency of switches required on a trial. The resulting correlations are shown in Table 2.

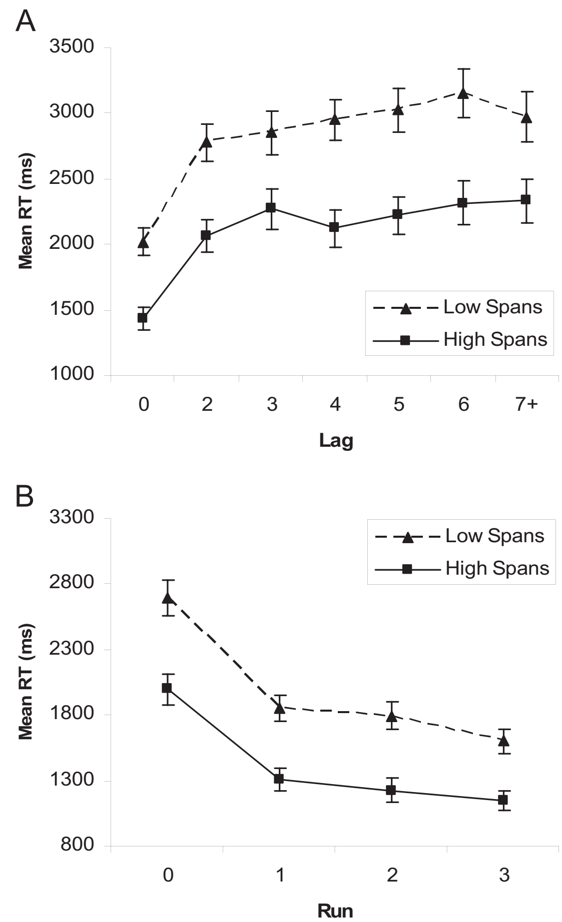

Figure 5. A: Response time (RT) as a function of lag since the last switch and working memory span. B: RT as a function of the number of runs before a switch and working memory span. Error bars represent one standard error of the mean.

The results of these correlation analyses are generally consistent with those of Experiment 1, suggesting that accuracy of the counts is related to performance on the Raven, but the speed of switching between counts is related neither to overall accuracy on the counts nor to performance on the Raven. Once again, focus-switching accuracy but not focus-switching speed was related to gF.

Discussion

The results for Experiment 2 were largely consistent with the results from Experiment 1. As in Experiment 1, low span partic-

Table 2
Experiment 2: Correlations for Accuracy and Switch Costs in the Counting Task With Raven

Variable	1	2	3	4	5
1. Raven	—				
2. MFacc	.34*	—			
3. HFacc	.53**	.80**	—		
4. MFcost	−.15	.22	.21	—	
5. HFcost	−.25	.14	.10	.87**	—

Note. MF = Medium frequency switch trial; acc = accuracy; HF = high frequency switch trial; cost = switch costs.
* $p < .05$. ** $p < .01$.

ipants were more inaccurate in their counts than high span participants; increasing the number of switches that were required on a trial decreased accuracy for low span participants but had no effect on high span participants. Also, as in Experiment 1, switch trials were much slower than nonswitch trials, and this changed as a function of the frequency of switches on the trial. Crucially, and consistent with Experiment 1, high and low spans did not differ in their switch costs (although low spans were slower overall). Lag and run analyses suggested that participants were fastest on nonswitch trials and equally slow on switch trials, regardless of the lag.

Additionally, consistent with Experiment 1, the correlation analyses suggested that speed and accuracy were not correlated and that performance on the Raven was correlated only with the accuracy of the counts and not with the RT associated with switching counts. This suggests that the ability to switch to relevant information outside of the focus of attention is related to WM span and gF, but the time to switch to relevant information outside of the focus of attention is not.

Experiment 3

Experiment 3 was conducted to examine the relation between focus switching (switching between objects) and task switching (switching between operations performed on the objects). As noted previously, task switching has recently been a heavily studied topic (see Monsell, 2003, for a review), yet only a few studies have examined the extent to which focus switching and task switching represent the same or different constructs (e.g., Verhaeghen & Hoyer, 2007). We sought to examine whether focus switching was distinct from task switching and whether task switching would be related to WM span or gF. Previous work has suggested that task switching is not related to either WM span (Oberauer, Süß, Wilhelm, & Wittmann, 2003) or gF (Friedman et al., 2006), similar to the results obtained for focusing switching. Thus, Experiment 3 was conducted to examine the relations between all constructs (focus–object switching, task switching, WM span, and gF). Participants performed the same version of Garavan's counting task as in Experiment 1 (minus the low frequency switch condition), but here participants could either add the current object to the current count or subtract the current object from the current count. Specifically, if participants saw a big square with a plus sign above it, they were instructed to increment the big square count by 1. If they saw a big square with a minus sign above it, they were to subtract 1 from the current big square count. Thus, participants not only switched between objects (big vs. small squares), but also switched between tasks performed on those objects (addition vs. subtraction). As before, the frequency of object switches was also manipulated (medium vs. high).

Participant Screening for WM Span and Raven Progressive Matrices

All participants were prescreened on three complex memory span measures: Ospan, reading span, and symmetry span. All three tasks are computer administered and allow for group testing (e.g., Unsworth et al., 2005). The tasks have been shown to have good reliability (e.g., Cronbach's α estimates = .78–.86), and they have been found to be highly correlated with one another and to load on the same basic factor (see Kane et al., 2004). Individuals were selected on the basis of a *z*-score composite of the three tasks. Only participants who fell in the upper (high spans) and lower (low spans) quartiles of the composite distribution were selected.

Ospan. The same version was used as in Experiment 2. The score was the proportion of correct items in the correct position.

Reading span. In this task, participants were required to read sentences while trying to remember the same set of unrelated letters as in the Ospan. For this task, participants read a sentence and determined whether the sentence made sense or not (e.g., *The prosecutor's dish was lost because it was not based on fact. ?*). Half of the sentences made sense, whereas the other half did not. Nonsense sentences were made by simply changing one word (e.g., *case* to *dish*) in an otherwise normal sentence. There were 10–15 words in each sentence. Participants were required to read the sentence and to indicate whether it made sense or not. After participants gave their response, they were presented with a letter for 1 s. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters. There were three trials of each set size with list length ranging from three to seven items. The same scoring procedure as for Ospan was used.

Symmetry span. In this task, participants were required to recall sequences of red squares within a matrix while performing a symmetry-judgment task at the same time. In the symmetry-judgment task, participants were shown an 8 × 8 matrix with some squares filled in black. Participants decided whether the design was symmetrical about its vertical axis. The pattern was symmetrical half of the time. Immediately after determining whether the pattern was symmetrical, participants were presented with a 4 × 4 matrix with one of the cells filled in red for 650 ms. At recall, participants recalled the sequence of red-square locations in the preceding displays in the order they appeared by clicking on the cells of an empty matrix. There were three trials of each set size, with list length ranging from two to five items. The same scoring procedure as for Ospan was used.

Composite Score

For the composite score, scores for each of the three complex span tasks were *z*-transformed for each participant. These *z*-scores were then averaged together and quartiles were computed from the averaged distribution. This distribution consisted of scores for over 600 individual participants who completed each of the three span tasks. High and low spans in the current study were selected from the top and bottom quartiles of this overall distribution. Additionally, participants were selected only if they maintained 80% accuracy on the processing component across the three span tasks. Participants also completed the same version of the Raven Progressive Matrices as used in Experiment 2.

Method

Participants and design. Participants were 25 high and 23 low spans, as determined by *z*-score composite of the three span tasks. Participants were recruited from the subject pool at Georgia Institute of Technology and from the Atlanta community through newspaper advertisements. They were between the ages of 18 and 35 and received either course credit or monetary compensation for their participation. Each participant was tested individually in a laboratory session lasting approximately 45 min. The design was a 2 (span: high vs. low) × 2 (frequency: high and medium) × 2 (switch: switch vs. nonswitch) × 2 (switch type: object vs. task) mixed factorial design, with frequency, switch, and switch type as the within-subjects variables.

Procedure. After signing informed consent, participants were provided with instructions of the task procedure. Each trial began by presenting the participant with a fixation point on screen for 150, 300, or 600 ms, followed by either a big square or a small square. The participants' task was to keep running counts of the number of big and small squares they saw (as in Experiment 1). However, unlike Experiments 1 and 2, here an object was either added to the current count or subtracted from the current count, on the basis of whether the object was accompanied by a plus sign (+) that indicated that the object should be added to the current count or a minus sign (−) that indicated that the current object should be subtracted from the current count. Thus, in this experiment there were both object switches as in the previous experiments and task switches in which the operation performed on an object could change (either addition or subtraction). With the presentation of each object, participants performed the current operation on the object and rehearsed the other count, similar to Experiments 1 and 2. Participants were instructed to be as fast and accurate as possible while counting. Participants pressed the spacebar to advance the screen forward during the counts and entered in their final counts at the end of each trial. The order of recall was big squares and then small squares, similar to Experiment 1.

The task consisted of 2 practice trials and 26 real trials. A trial consisted of 11–15 (345 total) squares and two accuracy screens. In total there were 216 object nonswitch subtrials and 129 object switch subtrials, as well as 159 (99 object nonswitch subtrials, 60 object switch subtrials) task nonswitch subtrials and 186 (117 object nonswitch subtrials, 69 object switch subtrials) task switch subtrials. Additionally, there were 13 trials for each of the two frequency conditions (high and medium).

Results

Participants. Data for 1 low span participant were excluded from data analyses due to low accuracy rates on both counts (i.e., less than 30% on both counts). The mean *z*-scores for the final 25 high and 22 low spans were 0.97 (SD = 0.15, range = 0.71–1.28) and −0.92 (SD = 0.38, range = −1.8–0.53).

Accuracy. Overall accuracy levels were high (M = 0.91, SE = 0.01) and were the same for big and small squares (M = 0.90, SE = 0.01 vs. M = 0.91, SE = 0.02). Consistent with Experiments 1 and 2, frequency of switches negatively impacted the accuracy of the counts, with medium frequency switch trials being more accurate (M = 0.92, SE = 0.02) than high frequency switch trials (M = 0.89, SE = 0.01). High span participants were also more accurate than low span participants (M = 0.95, SE = 0.02 vs. M = 0.86, SE = 0.02). However, unlike Experiments 1 and 2, there was no effect of object, nor did span and frequency seem to interact.

These observations were supported by a 2 (span: high vs. low) × 2 (object: big vs. small) × 2 (frequency: medium vs. high) mixed ANOVA, with object and frequency as the within-subjects factors. The ANOVA demonstrated main effects of frequency, $F(1, 45) = 8.03$, $MSE = 0.006$, $p < .01$, partial $\eta^2 = .15$, and span, $F(1, 45) = 11.75$, $MSE = 0.05$, $p < .05$, partial $\eta^2 = .21$. There were also significant interactions involving span and object, $F(1, 45) = 4.36$, $MSE = 0.006$, $p < .01$, partial $\eta^2 = .09$, and object and frequency, $F(1, 45) = 7.35$, $MSE = 0.006$, $p < .01$, partial $\eta^2 = .14$. These interactions suggested that accuracy did not change for low spans (M Big = 0.87, SE = 0.02 vs. M Small = 0.86, SE = 0.02), $F < 1$, but that high spans had more accurate small square counts than big square counts (M Big = 0.93, SE = 0.02 vs. M Small = 0.97, SE = 0.02), $F(1, 24) = 16.30$, $MSE = 0.001$, $p < .01$, partial $\eta^2 = .40$. Additionally, the accuracy of small square counts did not change as a function of frequency (M Medium = 0.92, SE = 0.02 vs. M High = 0.91, SE = 0.02), $F < 1$, but the accuracy of big square counts did (M Medium = 0.93, SE = 0.01 vs. M High = 0.87, SE = 0.01), $F(1, 46) = 19.45$, $MSE = 0.004$, $p < .01$, partial $\eta^2 = .30$.

The majority of the counts were under the correct value (64.5%) and within ±1 of the correct value (78.5%). Furthermore, this did not seem to differ as a function of span, with the majority of both high and low span participants' counts being under the correct value (64.8% vs. 64.3%) and within ±1 of the correct value (88.5% vs. 73.3%). Thus, although low spans are more likely than high spans to be incorrect in their counts, both high spans and low spans tend to be under the correct value by one.

Response time. Consistent with previous work, responses were slower on object switch trials than on object nonswitch trials (overall object switch cost = 338 ms) and were slower on task switch trials than on task nonswitch trials (overall task switch cost = 153 ms). Additionally, the frequency of object switches required on a trial impacted the magnitude of the object switch cost such that object switch costs were smallest on high frequency switch trials (object switch cost = 260 ms) compared to medium frequency switch trials (switch cost = 417 ms). Finally, and consistent with the previous experiments, the only effect of WM span was a slight difference between high and low span individuals on RT for high frequency switch trials; there were no differences in RT on medium frequency switch trials, and no differences in any of the switch costs (high object switch cost = 331 ms vs. low object switch cost = 346 ms; high task switch cost = 151 ms vs. low task switch cost = 154 ms). Thus, consistent with Experiments 1 and 2, although there were prominent effects of frequency and types of switches on RT, high and low span individuals tended to have fairly similar RTs.

These conclusions were supported by a 2 (span: high vs. low) × 2 (frequency: medium vs. high) × 2 (object switch: switch vs. nonswitch) × 2 (task switch: switch vs. nonswitch) mixed ANOVA, with frequency, object switch, and task switch as the within-subjects factors. The ANOVA demonstrated main effects of object switch, $F(1, 45) = 264.01$, $MSE = 40{,}550$, $p < .01$, partial $\eta^2 = .86$, and task switch, $F(1, 45) = 82.80$, $MSE = 26{,}583.56$, $p < .01$, partial $\eta^2 = .65$, indicating that responses were slower on switch trials than nonswitch trials. There were also significant two-way interactions involving frequency and span, $F(1, 45) = 4.00$, $MSE = 10{,}777$, $p = .051$, partial $\eta^2 = .08$, and frequency and object switch, $F(1, 45) = 47.29$, $MSE = 12{,}229$, $p < .01$, partial $\eta^2 = .51$. The span by frequency interaction suggested that low spans were slightly slower on medium frequency switch trials than high frequency switch trials (*M* Medium = 1,575, *SE* = 87 vs. *M* High = 1,557, *SE* = 87), whereas the converse was true for high spans (*M* Medium = 1,518, *SE* = 82 vs. *M* High = 1,543, *SE* = 82). The frequency by object interaction suggested that, similar to Experiment 1, object switch costs were smaller on high frequency switch trials than on low frequency switch trials. It is interesting that the object by task interaction was not significant, $F(1, 45) = 0.093$, $MSE = 14{,}655$, $p > .76$, partial $\eta^2 = .002$, suggesting that object switching and task switching are independent. Specifically, the results suggested that regardless of whether there was a task switch, object switch costs were roughly 340 ms, whereas task switch costs were roughly 150 ms regardless of whether there was an object switch. No other effects reached conventional levels of significance, all *F*s < 1.

Lags and runs. The effects of lag were largely similar to the previous experiments. Here there were six levels of lag (0, 1, 2, 3, 4, 5). The lag functions are shown in Figure 6A collapsed on frequency condition. Similar to Experiment 2, the largest difference between the different lags occurred for the Lag 0 versus all the other lags (the switch cost), whereas there were slight differences between the other lags.

An examination of runs suggested results largely similar to the previous experiments (see Figure 6B). Specifically, a run of zero (a switch trial) was associated with the slowest RTs, and then RTs speeded up slightly. These observations were supported by a 2 (span: high vs. low) × 4 (run: 0, 1, 2, 3) mixed ANOVA, with run as the within-subjects factor. The only significant effect was a main effect of run, $F(4, 180) = 78.40$, $MSE = 45{,}454$, $p < .01$, partial $\eta^2 = .64$. All other effects were associated with *F*s < 1.

Correlations. Next we examined the correlations between the different switch costs and accuracy of the counts and correlations with performance on the Raven. Object switch costs were computed by subtracting trials in which no switch occurred (neither an object nor a task switch) from trials in which only an object switch occurred. Task switch costs were computed by subtracting trials in which no switch occurred (same trials used to compute the object switch costs) from trials in which only a task switch occurred. Thus, it should be noted that object switch costs and task switch costs are related because they were partially computed from the same trials.[1] In addition, note that Raven data were available for only 46 of the current participants. The correlations suggested that mean accuracy of the counts was once again related to performance on the Raven ($r = .61$, $p < .01$), but neither the mean object switch cost ($r = .09$, $p > .56$) nor the mean task switch cost was related to performance on Raven ($r = .02$, $p > .91$). In addition, neither the object switch cost ($r = .08$, $p > .58$) nor the task switch cost ($r = -.01$, $p > .96$) was related to the accuracy of the counts. However, the two switch costs were related ($r = .65$, $p < .01$), although, as noted above, this is partially because the same responses were used to compute the switch costs. As with the previous experiments, the correlations were further examined as a function of the frequency of the object switches required on a trial. The resulting correlations are shown in Table 3.

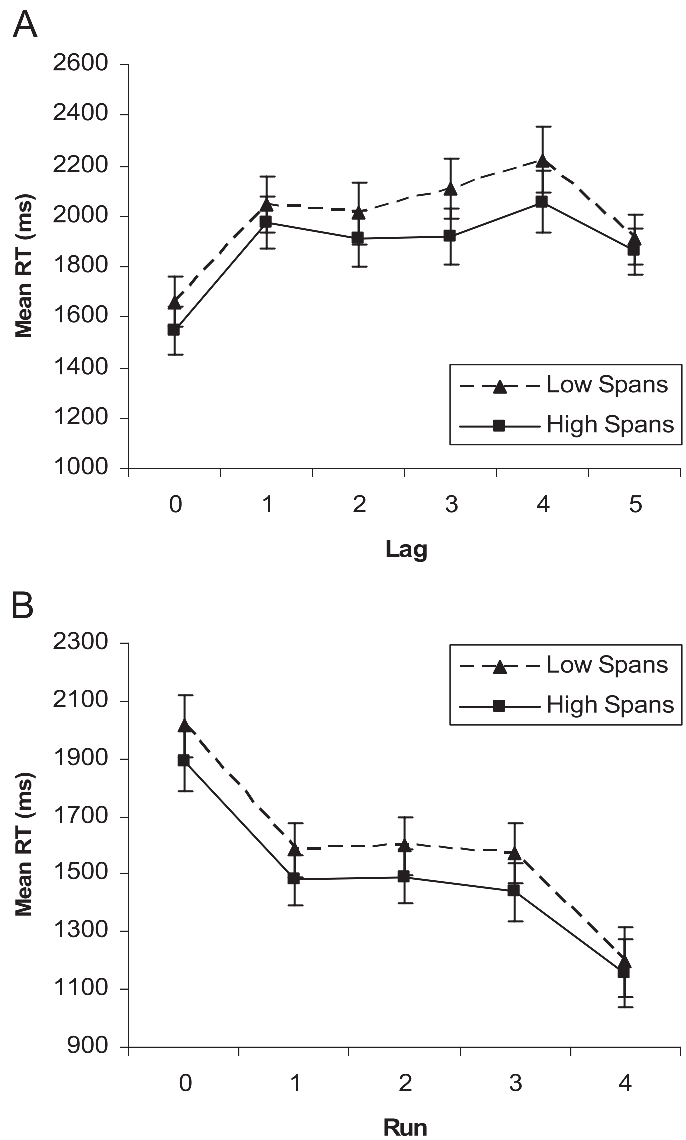

Figure 6. A: Response time (RT) as a function of lag since the last switch and working memory span. B: RT as a function of the number of runs before a switch and working memory span. Error bars represent one standard error of the mean.

Like the previous experiments, these correlations suggest that the accuracy of the counts is related to performance on Raven, but neither the ability to switch between different objects nor the ability to switch between different operations performed on those objects is related to performance on the Raven.

[1] Both object and task switch costs were also computed, regardless of whether the other switch type occurred, and the correlations were virtually identical to those reported.

Table 3
Correlations for Accuracy, Object Switch Costs, and Task Switch Costs in the Counting Task With Raven

Variable	1	2	3	4	5	6	7
1. Raven	—						
2. MFacc	.48**	—					
3. HFacc	.66**	.72**	—				
4. ObMFcost	.08	−.01	.13	—			
5. ObHFcost	.06	.02	.14	.38**	—		
6. TskMFcost	−.15	−.14	−.07	.45**	.38**	—	
7. TskMFcost	.15	.03	.13	.41**	.62**	.49**	—

Note. MF = medium frequency switch trial; acc = accuracy; HF = high frequency switch trial; Ob = object switch; cost = switch costs; Tsk = task switch.
** $p < .01$.

Discussion

Overall the results of this experiment were in line with the previous experiments suggesting that the accuracy of the counts is related to both WM span and performance on the Raven. Once again, neither WM span nor Raven was associated with the time needed to switch between objects. New to this study was the finding that task switching (switching between operations performed on an object) also was not related to either WM span or performance on the Raven. Thus, the speed with which switching operations (either object switching or task switching) are carried out is not related to either WM span or gF.

General Discussion

In three experiments, individual differences in the speed and accuracy of switching the focus of attention were investigated in terms of their relation with WM and gF. A number of consistent findings arose in all three experiments. First, there was a substantial time cost associated with switching between objects, and this time cost varied as a function of the number of switches that were required on a particular trial. In particular, switch costs were largest when there were large runs of the presentation of the same object, suggesting that stimulus repetition effects partially determine the magnitude of the switch cost (see also Gehring, Bryck, Jonides, Albin, & Badre, 2003). Second, individual differences in WM span and gF (as measured by the Raven) were not associated with this time cost in any experiment. That is, although there were individual differences in switch costs, these differences were unrelated to WM and gF. Third, both WM span and gF were substantially related to the accuracy of the counts, especially when many switches were required. That is, accuracy tended to decrease as the frequency of object switches increased, and this impacted low-ability individuals more than high-ability individuals. Taken together, these results suggest that it takes time to switch the focus of attention between objects in WM, and the more times individuals have to switch the focus between objects, the more likely they are to switch to the wrong representation. Consistent with previous work by Verhaeghen and colleagues (Verhaeghen & Basak, 2005; Verhaeghen & Hoyer, 2007), the current results suggest that focus switching is an important ability that is related to other individual difference variables. Novel to the current study is the finding that variation in WM span and gF is related to the accuracy of the switching mechanism, but not to the speed of the switching mechanism. This suggests that individual differences in WM span are partially due to differences in the accuracy of a switching mechanism that retrieves relevant representations in WM that are outside of the focus of attention, but these differences are not related to the speed of that mechanism. Additionally, the results of Experiment 3 suggest that variation in WM and gF is also not related to the time cost associated with switching between operations performed on an object. Thus, WM and gF are not related to task switching speed.

These results are consistent with prior work suggesting that variation in WM is related to the ability to retrieve relevant representations from outside of the focus of attention in the presence of multiple irrelevant representations (e.g., Unsworth & Engle, 2007), but variation in WM is not related to the speed of switching abilities (i.e., task switching; Oberauer et al., 2003). These results are also consistent with additional work that has used versions of this counting task to examine the differential predictive power of the time and accuracy of switching the focus of attention. Specifically, Holden, Biesanz, and Postle (2004) examined the extent to which various executive function tasks were related to one another and related to measures of gF in a large correlational study. It is important to note that Holden et al. (2004) examined speed and accuracy in a version of the continuous counting task used in the current experiment as well as a version of the Ospan and two measures of gF (including the Raven). Consistent with the present results, Holden et al. (2004) found that accuracy in the continuous counting task was significantly related to both Ospan and the measures of gF, whereas the time costs associated with switching the focus of attention were not. In addition, Holden et al. found that the accuracy of the continuous counting task was related to other executive function tasks, including a traditional running memory span task, a running memory span task with a high level of proactive interference, and a dichotic listening task. The switch costs, however, were not substantially related to any of the other executive function tasks.

Collectively these results suggest that one important ability indexed by WM span tasks and one reason that they correlate with measures of higher order cognitive functioning (such as the Raven) is the ability to switch to and retrieve relevant information from outside of the focus of attention in the presence of irrelevant information. Recently, we (Unsworth & Engle, 2007) have advanced a model of individual differences in WM based on differences in the ability to maintain representations in the focus of attention and differences in the ability to retrieve items from outside of the focus of attention. This view—which is based on models of Cowan (1988), Oberauer (2002), and McElree (2001) discussed previously—suggests that individual differences in WM arise in many situations due to differences in the ability to correctly retrieve items from outside of the focus of attention back into the focus of attention for report. The key to successful retrieval, we argued, is the ability to correctly differentiate target representations from other recently presented nontarget representations. The results of the current experiments are consistent with this notion, suggesting that retrieval accuracy of information outside of the attentional focus is important, but the speed of retrieval is not.

Limitations, Alternative Explanations, and Future Directions

Perhaps the biggest limitation and possible alternative explanation for the current results is the possibility of a speed–accuracy tradeoff and the possibility that high and low spans differ in their speed–accuracy tradeoff functions. This is especially concerning because the task used in all three experiments was self-paced, and the instructions specified that participants should be as fast and accurate as possible. It is possible, therefore, that low spans sacrificed accuracy for speed and thus pushed the effect of span differences into the accuracy domain. To examine this possibility, we looked at the correlation between overall speed and overall accuracy in all three experiments. If it is the case that participants are trading off accuracy for speed (or vice versa), then overall speed and accuracy should be negatively correlated. However, in all three experiments there was virtually no correlation between speed (i.e., overall mean RT) and accuracy (i.e., overall mean accuracy) levels (i.e., E1 $r = .14$, $p > .31$; E2 $r = -.15$, $p > .27$; E3 $r = .00$, $p > .98$). Note these correlations were computed across all participants regardless of WM span. Thus, it is unlikely that participants were trading accuracy for speed in this task and this somehow biased the results.

A second limitation and potential alternative explanation is that because in each experiment participants were required to report their counts in fixed order, it is possible that output interference affected the results and could have contributed to the differences between the span groups. Specifically, in Experiments 1 and 2 accuracy was worse for counts reported later in the recall sequence than counts reported first. Additionally, the accuracy of low span individuals' counts in Experiment 2 was worse later in the recall sequence than counts reported first. Thus, this suggests that output interference could have reduced the accuracy of some of the counts, and this may have affected low span individuals more so than high span individuals. However, these effects were neither particularly strong in these experiments nor were they very systematic, as indicated by the fact that there was no overall difference between counts in Experiment 3, and span differences consistent with output interference only occurred in Experiment 2. In fact, span differences were also found in Experiment 3, but in the wrong direction. Specifically, in Experiment 3 there was no difference in the accuracy of the counts for low span individuals, and accuracy for high span individuals' second count was higher than accuracy for their first count. Thus, although output interference may have affected some of the results, it does not appear that the effect was particularly strong or systematic in terms of individual differences in WM.

Another limitation of the current study, and indeed of many studies in this line of research, is the reliance on extreme groups and the possible problems that this entails. In particular, it is well known that the use of extreme groups can inflate effect sizes, thereby biasing one to find an otherwise small effect (Conway et al., 2005; Preacher, Rucker, MacCallum, & Nicewander, 2005). Clearly it is preferable to use the whole distribution of participants (and not just the extreme tails) whenever possible; however, as we have pointed out previously (Conway et al., 2005; Unsworth, Schrock, & Engle, 2004), the benefit of using these extreme-groups designs is to determine if a relationship (between WM and some other variable) exists in the first place, regardless of its magnitude. If such a relationship is found via an extreme-groups analysis, then future studies can assess the magnitude of this relationship as well as possible mediators and moderators of this relationship using the full distribution of scores. Thus, although extreme-groups designs certainly have their problems, they are also beneficial in exploring whether a relation exists in the presence of many experimental variables.

Finally, it is clear that results of the current study are open to a host of potential alternative explanations; the explanation of individual differences in the ability to retrieve relevant information among irrelevant information is simply our current preferred explanation. That is, the results of the current study do not conclusively point to the ability to retrieve information from outside the focus of attention as the critical difference between high and low span individuals; rather, the results of the current study are merely consistent with that notion. At the very least, the results indicate that the accuracy of focus switching is related to WM and gF, but the speed of focus switching is not. This suggests that the ability to accurately shunt information in and out of the focus of attention is an important ability that is related to other well-known cognitive abilities. The speed of this shunting mechanism, however, is not related to these other abilities.

Clearly, future work is needed to better examine the notion that individual differences in WM are related to differences in switching and retrieval of information outside of the focus of attention. This work could include examinations of high and low span differences in other focus-switching tasks such as those used by Oberauer (2002), Verhaeghen and colleagues (Verhaeghen & Basak, 2005; Verhaeghen & Hoyer, 2007), and McElree (2001). These tasks have the benefit of allowing for a better examination of item-level effects and more stringent experimental control over speed and accuracy as well as output interference. Finally, future work should be directed at examining the extent to which these various focus-switching tasks are related to one another, to multiple measures of WM, and to other cognitive abilities constructs. Via a combined experimental and differential approach, we should be able to better elucidate the nature of individual differences in these cognitive functions.

Conclusion

The results from three experiments suggested that individual differences in WM and gF are related to the accuracy of switching the focus of attention to representations outside of the focus. In all three experiments there were pronounced differences in the accuracy of counts in a continuous counting task, with low-ability individuals being more inaccurate in their counts than high-ability individuals. However, the time cost associated with switching the focus of attention was not related to either WM or gF in any experiment. Furthermore, the time cost associated with switching operations performed on the counts (task switching) was also not related to either WM or gF. Taken together, these results suggest that individual differences in WM and gF are related to the accuracy of focus switching, but are not related to the speed of switching the focus of attention.

References

Anderson, J. R. (1983). *The architecture of cognition.* Cambridge, MA: Harvard University Press.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence (Ed.), *The psychology of learning and motivation* (Vol. 2, pp. 89–195). New York: Academic Press.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12,* 769–786.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin, 104,* 163–191.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences, 24,* 97–185.

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. Ross (Ed.), *The psychology of learning and motivation* (Vol. 44, pp. 145–199). New York: Elsevier.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General, 128,* 309–331.

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science, 17,* 172–179.

Garavan, H. (1998). Serial attention within working memory. *Memory & Cognition, 26,* 263–276.

Garavan, H., Ross, T. J., & Stein, E. A. (2000). A parametric manipulation of central executive functioning. *Cerebral Cortex, 10,* 585–592.

Gehring, W. J., Bryck, R. L., Jonides, J., Albin, R. L., & Badre, D. (2003). The mind's eye looking inward? In search of executive control in internal attention shifting. *Psychophysiology, 40,* 572–585.

Holden, R. J., Biesanz, J. C., & Postle, B. R. (2004, November). *The unitary/nonunitary nature of executive control.* Poster session presented at the annual meeting of the Psychonomic Society, Minneapolis, MN.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working-memory capacity: A latent-variable approach to verbal and visuo-spatial memory span and reasoning. *Journal of Experimental Psychology: General, 133,* 189–217.

Klein, K., & Fiss, W. H. (1999). The reliability and stability of the Turner and Engle working memory task. *Behavioral Research Methods, Instruments, & Computers, 31,* 429–432.

Li, Z. H., Sun, X. W., Wang, Z. X., Zhang, X. C., Zhang, D. R., He, S., & Hu, X. P. (2004). Behavioral and functional MRI study of attention shift in human verbal working memory. *NeuroImage, 21,* 181–191.

McElree, B. (1998). Attended and non-attended states in working memory: Accessing categorized structures. *Journal of Memory & Language, 38,* 225–252.

McElree, B. (2001). Working memory and focal attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 817–835.

McElree, B. (2006). Accessing recent events. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 46, pp. 155–200). San Diego, CA: Academic Press.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7,* 134–140.

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28,* 411–421.

Oberauer, K. (2003). Selective attention to elements in working memory. *Experimental Psychology, 50,* 257–269.

Oberauer, K., Süß, H.-M., Wilhelm, O., & Wittmann, W. W. (2003). The multiple faces of working memory—storage, processing, supervision, and coordination. *Intelligence, 31,* 167–193.

Preacher, K. J., Rucker, D. D., MacCallum, R. C., & Nicewander, W. A. (2005). Use of extreme groups approach. A critical reexamination and new recommendations. *Psychological Methods, 10,* 178–192.

Raven, J. C., Raven, J. E., & Court, J. H. (1998). *Progressive matrices.* Oxford, England: Oxford Psychologists Press.

Rogers R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124,* 207–231.

Towse, J. N., Hitch, G. J., & Hutton, U. (2000). On the interpretation of working memory span in adults. *Memory & Cognition, 28,* 341–348.

Towse, J. N., Hitch, G. J., & Hutton, U. (2002). On the nature of the relationship between processing activity and item retention in children. *Journal of Experimental Child Psychology, 82*(2), 156–184.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28,* 127–154.

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review, 114,* 104–132.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods, 37,* 498–505.

Unsworth, N., Schrock, J. C., & Engle, R. W. (2004). Working memory capacity and the antisaccade task: Individual differences in voluntary saccade control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 1302–1321.

Verhaeghen, P., & Basak, C. (2005). Ageing and switching of the focus of attention in working memory: Results from a modified N-back task. *Quarterly Journal of Experimental Psychology, 58*(A), 134–154.

Verhaeghen, P., & Hoyer, W. J. (2007). Aging, focus switching and task switching in a continuous calculation task: Evidence toward a new working memory control process. *Aging, Neuropsychology, and Cognition, 14,* 22–39.

Received March 23, 2007
Revision received January 8, 2008
Accepted January 15, 2008 ■