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Variation in working memory capacity and intrusions: Differences in generation or editing?

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The current study explored the reason for the relation between individual differences in working memory capacity (WMC) and intrusions in free recall. High and low WMC individuals were tested in standard delayed free recall and externalised free recall in which participants recalled everything that came to mind. Additionally, in externalised free recall participants were instructed to press a key for each item that they knew was an intrusion. In delayed free recall, low WMC individuals recalled fewer correct items and more previous list and extralist intrusions than high WMC individuals. In externalised free recall, differences only arose in previous list intrusions. Furthermore, in externalised free recall it was found that low WMC were less likely to identify both types of intrusions than high WMC individuals. It is argued that the reason low WMC individuals recall more intrusions than high WMC in free recall is due to differences in both generation and editing abilities.

Keywords: Working memory; Free recall; False memory; Intrusions.

Individual differences in working memory capacity (WMC) have been shown to be important in a number of basic memory tasks including cued recall, serial recall, free recall, and even recognition (see Unsworth & Engle, 2007, for a review). In nearly all of these tasks individuals who score high on measures of WMC (typically complex span tasks) recall more correct items than individuals who score low on measures of WMC. That is, high WMC individuals tend to have more veridical memories than low WMC individuals. At the same time, a number of recent studies have suggested that individual differences in WMC are also related to "false memories" as indicated by a greater tendency of low WMC individuals to recall more intrusions (items not presented on the current list) than high WMC individuals. For instance, a number of studies have shown that low WMC individuals make more

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intrusions in cued recall (Rosen & Engle, 1998), and free recall (Unsworth, 2007), DRM word lists with prior warnings (Watson, Bunting, Poole, & Conway, 2005), as well as in the complex span tasks themselves (Unsworth & Engle, 2006). Furthermore, other groups thought to be low in WMC also tend to recall many more intrusions than groups thought to be high in WMC including older adults (de Beni & Palladino, 2004; Kahana, Dolan, Sauder, & Wingfield, 2005) and individuals with reading disabilities (Chiappe, Hasher, & Siegel, 2000). As such, these results suggest that in order to understand individual differences in WMC and their relation to broader memory constructs, it is important to examine both correct responses and error responses (particularly intrusions).

Generate-edit models of free recall (Anderson & Bower, 1972; Raaijmakers & Shiffrin, 1980; Sirotin, Kimball, & Kahana, 2005) readily explain intrusions in free recall by assuming that initially participants sample items from a search set of possible items that include both target representations and intrusions. After an item has been sampled, it is subjected to an editing process. If the item is deemed as correct it is overtly recalled. If it is deemed as incorrect it is not recalled. Thus, intrusions arise from first sampling an incorrect item, and then incorrectly deciding that the item is correct and recalling it. This suggests a failure of both processes is needed for an intrusion to occur.

In terms of individual differences in WMC and intrusions, generate-edit models suggest three possible ways that these differences can arise. First, it is possible that low WMC individuals simply include many more intrusions in their search sets than high WMC individuals with little or no differences in editing processes (Unsworth, 2007). For instance, if both high and low WMC individuals have an editing process that works 80% of the time and low WMC individuals generate 15 intrusions, then they will catch 12 of those before being overtly recalled, but will incorrectly allow 3 of them to be recalled. If high WMC individuals only generate 10 intrusions, then they will catch 8 of those, but will overtly recall 2, leading to differences. Thus, it is possible that individual differences in WMC and intrusions are entirely due to differences in the number of intrusions that are generated, with no differences in editing. These differences in the number of intrusions that are included in the search set and generated could arise either due to differences in the specificity of the cues used to focus the search set (Unsworth, 2007) or due to differences in inhibitory control in which intrusions are inhibited (Hasher, Lustig, & Zacks, 2007).

Alternately, it is possible that high and low WMC individuals generate the same number of intrusions, but low WMC individuals are poorer at editing them which leads to more intrusions. That is, high and low WMC individuals might differ in source monitoring abilities (Johnson, Hashtroudi, & Lindsay, 1993) in which low WMC individuals are less able to correctly identify the source of items than high WMC individuals. This difference in source monitoring abilities should lead to differences in intrusions. For instance, if low WMC individuals generate 10 intrusions and have an editing process that is 80% effective, they will recall 2 intrusions. If high WMC individuals generate the same number of intrusions, but have an editing process that is 95% effective, they will recall 0.5 intrusions. Thus, this possibility also predicts differences between high and low WMC individuals in intrusions, but for a reason other than differences in the number of generated intrusions. Finally, it is possible that high and low WMC individuals differ in both the generation and editing of intrusions.

In order to test these possibilities, a variant of an externalised free recall task was used. In externalised free recall tasks participants are instructed to recall all of the target items as well as any other words that come to mind during the recall phase (Bousfield & Rosner, 1970; Kahana et al., 2005; Roediger & Payne, 1985; Rosen & Engle, 1997). By allowing participants to recall all items that come to mind, the externalised free recall task serves to minimise the editing process by making recall uninhibited (Bousfield & Rosner, 1970), and thus allows for an examination of the number of intrusions that are potentially generated. Furthermore, in order to examine editing processes within externalised free recall, Kahana et al. (2005) instructed participants to press a key immediately after any response the participant knew was incorrect. Thus, in this version of externalised free recall participants are free to generate all items that come to mind (both correct and incorrect items) and can indicate whether they acknowledge the item as an error or a correct response.

If high and low WMC individuals differ only in the generation of intrusions, then low WMC individuals should generate more intrusions than high WMC individuals, but high and low WMC individuals should correctly acknowledge the same number of items. Conversely, if high and low WMC individuals differ only in monitoring abilities, then high and low WMC individuals should generate the same number of items, but low WMC individuals should acknowledge fewer of the intrusions as incorrect than high WMC individuals. Finally, if high and low WMC individuals differ in both generation and editing, then low WMC individuals should generate more intrusions and should acknowledge fewer intrusions than high WMC individuals.

To examine these possibilities, high and low WMC individuals performed a standard delayed free recall task and a variant of externalised free recall (Kahana et al., 2005). Delayed free recall was used to demonstrate differences in intrusions between high and low WMC individuals in the current sample in order to replicate and extend previous findings (Unsworth, 2007). The externalised free recall task was used as the primary means of testing the three possibilities. For both tasks responses were categorised as correct or incorrect. Incorrect responses were broken down into intrusions from previous lists (previous list intrusions; PLIs), intrusions not presented anywhere in the experiment (extralist intrusions; ELIs), or repetitions in which the correct response was already given in the current list. Intrusions were broken down into PLIs and ELIs in order to examine possible differences between the errors and WMC. Specifically, although the two intrusion types are likely highly correlated, there are also differences between them given that PLIs arise due to list-discrimination problems (at either generation or editing), whereas ELIs arise due to being semantically or phonologically related to some of the target items (Craik, 1968). Furthermore, prior work (Unsworth, 2007) found WMC differences in PLIs, but only a trend for ELIs. Thus, it is not clear whether WMC differences only occur for PLIs (due perhaps to list-discrimination failures) or whether differences will also occur for ELIs. Using externalised free recall to increase the number of overall intrusions should provide valuable information on similarities and differences between PLIs and ELIs and possible WMC differences.

METHODS

Participants and WMC screening

Participants were recruited from the participant pool at the University of Georgia. Individuals were selected based on a *z*-score composite of three complex span tasks. Only participants falling in the upper (high WMC individuals) and lower (low WMC individuals) quartiles of the composite distribution were selected.

Operation span (Ospan). 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, Y). Participants were required to solve a maths operation and after solving the operation 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 (3–7) 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, Heitz, Schrock, & Engle, 2005, for more details). Participants received three sets (of list length 2) of practice. For all of the span measures, items were scored if the item was correct and in the correct position. The score was the proportion of correct items in the correct position.

Reading span (Rspan). Participants were required to read sentences while trying to remember the same set of unrelated letters as 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, and the other half did not. Nonsense sentences were made by simply changing one word (e.g., "dish" from "case") from an otherwise normal 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 list length, with list length ranging from 3 to 7. The same scoring procedure as Ospan was used.

Symmetry span (Symspan). In this task participants were required to recall sequences of red squares within a matrix while performing a symmetry-judgement task. In the symmetry-judgement 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 list length, with list length ranging from 2 to 5. The same scoring procedure as 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. Participants were 34 high WMC individuals (z-WMC $= 0.89$, $SD = 0.17$) and 30 low WMC individuals (z-WMC $= -1.20$, $SD = 0.78$), as determined by the composite measure.

Delayed free recall procedure

In this task participants were given six lists of 10 words each. All words were common nouns that were presented for 1 s each. After each list presentation, participants engaged in a 16 s distractor task before recall: Participants saw 8 three-digit numbers appear for 2 s each, and were required to write the digits in ascending order. After the distractor task participants saw "???", which indicated that they should type as many words as they could remember from the current list in any order they wished. After typing each word, participants pressed ENTER to record their response. Participants had 45 s for recall.[1]

[1] Prior research has suggested that 45 s is ample time for free recall with the given list lengths for both high and low WMC individuals (Unsworth, 2007).

Externalised free recall procedure

The externalised free recall task was exactly the same as the delayed free recall task except that a separate set of nouns was used and instructions for the recall phase indicated that recall should be uninhibited. Specifically, participants were instructed to not only type all of the items from the most recent list as they could, but to also type any other words that came to mind during the recall phase even if they knew that the word was not presented on the most recent list. Furthermore, participants were instructed that if they typed a word that they knew was incorrect, then they should press the spacebar to indicate that it is incorrect prior to recording their response.

RESULTS

Delayed free recall

The first set of analyses examined WMC differences in correct and error responses in the delayed free recall task. Shown in Table 1 are the average total number of correct and error responses recalled by high and low WMC individuals. Error responses were classified as previous list intrusions (PLIs), extralist intrusions (ELIs), or repetitions. Consistent with previous research, low WMC individuals recalled fewer correct items than high WMC individuals, $t(62) = -3.23$, $p < .01$, $\eta^2 = .14$. Low WMC individuals also recalled more PLIs, $t(62) = 2.42$, $p < .05$, $\eta^2 = .09$, and ELIs, $t(62) = 3.14$, $p < .01$, $\eta^2 = .14$, than high WMC individuals. Both groups recalled an equivalent number of repetitions, $t(62) = 1.29$, $p > .20$, $\eta^2 = .03$. Thus, consistent with prior work, low WMC individuals recalled fewer correct items, but recalled more intrusions than high WMC individuals. Furthermore, the differences in intrusions occurred for both PLIs and ELIs. This is important because prior work (e.g., Unsworth, 2007; Unsworth & Engle, 2007) has shown differences in PLIs, but only a trend towards a difference in ELIs. The significant

TABLE 1
Mean number of correct and error responses for delayed free recall as a function of WMC

	Measures			
WMC	*Corr*	*PLI*	*ELI*	*Rep*
High	35.76 1.30)	0.65 (0.15)	1.15 (0.23)	0.56 (0.16)
Low	29.23 (1.56)	1.30 (0.23)	3.97 (0.92)	0.90 (0.21)

Corr = correct; PLI = previous list intrusion; ELI = extralist intrusion; Rep = repetition. Standard errors are in parentheses.

differences found in the current study are likely due to greater power obtained from slightly larger sample sizes and a larger number of lists at a given list length than has been used previously. Collectively these results demonstrate high and low WMC differences in intrusions in a normal free recall task.

Externalised free recall

Given the differences found in delayed free recall, the next set of analyses focused exclusively on WMC differences in externalised free recall.[2] Shown in Table 2 are the average total number of correct and error responses recalled by high and low WMC individuals. Again, error responses were classified as PLIs, ELIs, or repetitions. Consistent with the delayed free recall results, low WMC individuals recalled fewer correct items than high WMC individuals, $t(62) = -4.77$, $p < .01$, $\eta^2 = .27$. Low WMC individuals also generated more PLIs than high WMC individuals, $t(62) = 2.05$, $p < .05$, $\eta^2 = .06$. However, unlike delayed free recall there were no differences in the number of ELIs generated, $t(62) = -0.67$, $p > .51$, $\eta^2 = .01$. And there were no differences in the number of repetitions generated, $t(62) = -0.37$, $p > .71$, $\eta^2 = .00$. Thus, when recall was uninhibited low WMC individuals still recalled more PLIs than high WMC individuals, but the groups were not different in the number of ELIs recalled.

Next, for both the correct and error responses we examined the number of responses that were correctly acknowledged. The primary measure of interest was simply the difference between the total number of responses generated and the number of responses correctly acknowledged (i.e., associated with a press of the spacebar). If participants correctly acknowledged all of their correct responses (corr), then the difference score (corrdiff) should be zero. Anything above zero indicates the number of items that were not acknowledged. As can be seen, there was no difference between high and low WMC individuals in the number of correct items acknowledged as correct, $t(62) = -0.34$, $p > .74$, $\eta^2 = .00$. Put another way, both high and low WMC individuals correctly classified over 98% of their correct responses. There were, however, differences in the number of PLIs acknowledged with low WMC individuals misclassifying more PLIs than high WMC individuals, $t(62) = 2.66$, $p < .01$, $\eta^2 = .10$. That is, when a PLI was made, high WMC individuals correctly acknowledged 83% of those PLIs as being incorrect, but low WMC individuals only acknowledged 52% of those PLIs as being incorrect. Note that the correct

[2] Participants recalled significantly fewer items in externalised free recall compared to delayed free recall, $F(1, 62) = 26.74$, $p < .01$, perhaps due to the extra burden of having to indicate if the response was incorrect or not. This, however, did not differ as a function of WMC, $F(1, 62) = 1.56$, $p > .21$, indicating that any additional burden was the same for high and low WMC individuals.

TABLE 2
Mean number of correct responses, error responses, and correctly recognised correct and error responses in externalised free recall as a function of WMC

	Measures							
WMC	*Corr*	*Corrdiff*	*PLI*	*PLIdiff*	*ELI*	*ELIdiff*	*Rep*	*Repdiff*
High	31.68 (1.13)	0.35 (0.09)	0.33 (0.11)	0.06 (0.04)	22.38 (4.55)	2.21 (0.39)	0.50 (0.13)	0.44 (0.13)
Low	22.53 (1.59)	0.30 (0.13)	3.80 (1.80)	0.53 (0.18)	18.33 (4.06)	6.13 (1.34)	0.43 (0.12)	0.37 (0.11)

Corr = correct; PLI = previous list intrusion; ELI = extralist intrusion; Rep = repetition; diff = difference between total number of responses generated and number of responses correctly recognised. Standard errors are in parentheses.

classification estimate for high WMC individuals is somewhat conservative given that the high WMC individuals' PLI difference score was not significantly different from zero, $t(33) = 1.44$, $p > .16$, $\eta^2 = .06$. Thus, high WMC individuals correctly acknowledged nearly all of their PLIs as being incorrect. Additionally, there were differences in the number of ELIs acknowledged with low WMC individuals misclassifying more ELIs than high WMC individuals, $t(62) = 2.96$, $p < .01$, $\eta^2 = .12$. That is, when an ELI was made, high WMC individuals correctly acknowledged 91% of those ELIs as being incorrect, but low WMC individuals only acknowledged 67% of those ELIs as being incorrect. There were no differences in the number of repetitions that were misclassified, $t(62) = -0.43$, $p > .66$, $\eta^2 = .00$.

DISCUSSION

Previous research has shown that high and low WMC individuals differ in the number of intrusions they make (Rosen & Engle, 1998; Unsworth, 2007). This difference could be due to differences in generation, editing, or both. The current study examined intrusions in both delayed free recall and externalised free recall. Consistent with prior work, low WMC individuals recalled fewer correct items, but more intrusions (both PLIs and ELIs) than high WMC individuals in delayed free recall. Using an externalised free recall task in which participants were instructed to recall everything that came to mind during the recall period, indicated that low WMC individuals generated more PLIs than high WMC individuals, but there were no differences in either ELIs or repetitions. In fact, high WMC individuals generated a numerically greater number of ELIs than low WMC individuals. In terms of generate-edit models of free recall, these results suggest that high and low WMC individuals differ in PLIs partly due to differences in the number of PLIs generated (i.e., they are more susceptible to proactive interference). For ELIs, however, generation does not seem to differ for high and low WMC individuals. Examining differences in the number of errors correctly acknowledged as being incorrect, suggested differences between high and low WMC individuals for both PLIs and ELIs, with high WMC individuals correctly classifying more of their intrusions as being incorrect than low WMC individuals. Consistent with a generate-edit model of free recall, these results suggest that differences between high and low WMC individuals in both PLIs and ELIs are due to differences in their ability to correctly monitor their recall output and edit out incorrect responses. That is, for both intrusion types, high WMC individuals were much better at classifying their intrusions as being incorrect than low WMC individuals. In typical free recall tasks like delayed free recall, differences between high and low WMC individuals in the number of intrusions is partially due to the fact that high WMC individuals are better at monitoring the source of their recalls and subsequently editing out erroneous recalls. That is, high WMC individuals are less susceptible to proactive interference and are better at monitoring what interference they do have compared to low WMC individuals.

Before concluding, it would be remiss not to point out that one clear limitation of the current study was the reliance on extreme groups and the possible problems that this entails. Specifically, it is well known that the use of extreme groups can inflate effect sizes, thereby biasing one to find small effects (Conway et al., 2005). Clearly, whenever possible, it is preferable to use the whole distribution of participants. 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 WMC 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 as well as latent variables. Thus, although extreme groups designs are problematic, they are also beneficial in exploring whether a relation exists in the presence of many experimental variables.

In conclusion, the results of the present study suggest that differences between high and low WMC individuals in intrusions are due to differences in both generation and editing. Differences in PLIs arise due to low WMC individuals including more PLIs in their search sets and not editing them out as effectively as high WMC individuals. Differences in ELIs, on the other hand, arise only due to differences in editing and monitoring processes. Thus, it would seem that differences between high and low WMC individuals in intrusions are due to multiple factors. Low WMC individuals make more intrusions (PLIs) than high WMC individuals because they include more intrusions in their search sets possibly due to deficits in cue specificity processes (Unsworth, 2007) or inabilities in controlled inhibition (Hasher et al., 2007). Additionally, low WMC individuals make more intrusions (both PLIs and ELIs) than high WMC individuals because they are poorer at monitoring the products of retrieval and correctly recognising and editing out errors possibly due to deficits in source monitoring (Johnson et al., 1993). Future work is needed to examine the interplay of generation and editing processes in free recall and how they relate to individual and group differences.

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