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Differently confident: Susceptibility to bias in perceptual judgments of size interacts with working memory capacity

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Abstract Much prior research has shown that retrieval of information from long-term memory (LTM) can influence many aspects of complex cognition *in situ*. However, research also has shown that not all individuals manage information retrieved from LTM in equivalent fashions. Specifically, high working memory capacity (WMC) individuals have been shown to be better able to manage not only what information is retrieved from LTM, but also whether it is applied to the task-at-hand. As such, it is likely that WMC will interact with the biasing influences of prior knowledge on current task performance. In this series of studies, high and low WMC individuals were asked to make perceptual judgments of size that either did or did not activate biasing prior knowledge. Results indicate that when retrieving information from LTM, high WMC individuals are actually more susceptible to perceptual bias and also are erroneously more confident in the accuracy of their response. However, when no retrieval from LTM is necessary, this effect reverses. This suggests that high WMC individuals are indeed able to inhibit such biasing information; however, their overconfidence in the quality of information retrieved from their own LTM can make them susceptible to making errors in perceptual judgments.

Keywords Attention · Interactions with memory · Memory · Visual working and short-term memory · 2D shape and form

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The ability to learn and retain information for future use is perhaps one of the most critical functions executed within our cognitive system. This bidirectional relationship between our long-term store and the task-at-hand is captured in some form in all major models of memory, theoretical and computational, and for good reason. Quite simply, we are designed to learn, and it is the application of this learned information that enables us to perform tasks more efficiently and easily. For example, prior domain expertise can produce measureable performance many standard deviations above what is considered "normal" in memory and other complex tasks (Ericsson, Charness, Feltovich & Hoffman, 2006). Prior knowledge also can lead to enhancements in more low-level cognitive and perceptual tasks, as is the case with such classic examples as the word superiority and recognition effects (Meyer & Schvaneveldt, 1976).

While the effects of existing knowledge are usually viewed as positive, there also are several examples where the automatic application of such knowledge may be maladaptive, or at least less optimal. For example, expertise in a given content area can produce fixation in other overlapping areas, as is the case with high domain knowledge individuals being less able to complete the remote associates task due to induced mental set (Wiley, 1998). This also is consistent with problem-solving research that has found that mental sets, induced by prior knowledge, lead to less effective solution paths to simple problems (Luchins, 1942). Similarly, prior knowledge often is cited as a cause for the rise of distortions related to object perception. For example, prior expectations of the weight of a golf ball can produce inaccuracies in weight estimates for actual golf balls (Ellis & Lederman, 1998). Similarly, misestimating relative size in the Ebbinghaus illusion also has been strongly tied to the influence of prior knowledge (Doherty et al., 2010). Thus, the same automatic application of known information that enables more efficient performance can sometimes cause potential problems when misapplied. However, an interesting question is whether we are all equally susceptible to these negative effects of prior knowledge, specifically for perceptual judgments? Can one potentially mitigate or selectively manage the automatic application of prior knowledge, especially in cases where it may not be appropriate or optimal to use? Fortunately, it does appear that we can in fact manage some of this flow of information, as research has suggested that individuals differ in how they manage information in short-term memory (STM), and these critical differences may produce different likelihoods of biasing prior information influencing current perceptual judgments.

Working memory capacity

The theoretical construct of working memory capacity (WMC), originally proposed by Baddeley & Hitch (1974), consists of what are essentially several short-term domain stores (e.g., visuospatial sketch pad, phonological loop, etc.) that are managed by a central executive system. The central executive system is responsible for not only rehearsing/maintaining information within these loops but also is responsible for retrieving information from LTM to be placed within these short-term stores. Importantly, it is not differences in these short-term stores that drive observed relationships between WMC and complex performance, but rather differences in these executive capacities (Daneman & Merikle, 1996; Shelton, Elliott, Matthews, Hill & Gouvier, 2010). Thus, variation in WMC is strongly tied to differences in how well individuals can balance maintenance and retrieval in the face of competing tasks or interference. Differences in WMC have been connected to successful performance in several domains, including measures of reading (Daneman & Carpenter, 1980) and fluid intelligence (Cowan et al., 2005), and also have been connected to performance in lower level attentional tasks, such as the anti-saccade task (Unsworth, Schrock & Engle, 2004).

WMC also has been significantly implicated in theories of visual perception and visual short-term memories. For example, notions of perceptual binding (Wheeler & Treisman, 2002) and the formation of integrated objects (Luck & Vogel, 1997) within visual short-term memory (VSTM) have both been discussed as a function of these attentional limits. Furthermore, WMC has been implicated in the automatic tradeoff between the capacity and precision of VSTM. While certainly a contentious debate, with some suggesting that tradeoffs between capacity and accuracy are possible (Roggeman et al., 2014), while others claiming not (Zhang & Luck, 2011), generally both sides seem to acknowledge that WMC is at least related to management of the contents of VSTM through a top-down influence on the VSTM system (He, Zhang, Li & Guo, 2015). Importantly, as is suggested with other nonvisual tasks referenced above, this top-down control capacity is limited, and different task conditions may selectively impede an individuals' ability to exert this influence (Lien, Ruthruff & Naylor, 2014).

Interaction between working memory capacity and long-term memory

Critical to the issue of susceptibility to perceptual biases as a result of prior knowledge, individuals who differ in WMC have been shown to differentially manage information retrieved from long-term memory (LTM). As alluded to earlier, one of the primary functions of the executive system of WMC is to "override" automatic tendencies brought on by the interaction between prior experience and current environment (Unsworth & Engle, 2007). A salient demonstration of this fact is the differential sensitivity to proactive interference demonstrated by different WMC groups. Similarity between previous items and the current items can naturally impair recall of the current items, and this has been supported by numerous classic studies (Keppel & Underwood, 1962). High WMC individuals, however, are less sensitive to the buildup of proactive interference from previous list items, suggesting that they are engaging in active inhibitory processes to suppress the influence of these previous set items (Kane & Engle, 2000; Lustig, May & Hasher, 2001). In other words, higher WMC individuals are better able to deal with interfering information that is automatically retrieved from LTM and limit its influence on the current task performance.

This explanation also accounts for results on other tasks that likewise require the suppression of information automatically retrieved from prior knowledge. For example, high WMC individuals make fewer errors on the Stroop task (Kane & Engle, 2003), are less likely to hear their name in the unattended channel in a dichotic listening task (Conway, Cowan & Bunting, 2001), and also appear to be better insulated from the effects of stereotype threat (Schmader & Johns, 2003). In these cases, knowledge activated from LTM (i.e., the color word in the Stroop task, the participants' name in the dichotic listening task, or the negative stereotype in the case of stereotype threat) must be dealt with in order to successfully complete the task at hand. Similarly, higher WMC individuals are also less susceptible to intrusive thoughts that are not necessarily related to the task at hand (McVay & Kane, 2012), again suggesting the importance of managing *any* information retrieved from LTM, even when it is not at all activated by task context.

However, there does appear to be some suggestion that WMC also may interact with high levels of domain knowledge in a given area. For example, the notion of long-term working memory capacity (Ericsson & Kintsch, 1995) suggests that in cases of domain expertise, those higher in WMC are able to keep more information active and available to consciousness because of a greater appreciation for relational structures in existing knowledge. In other words, rather than merely focusing on individual problem characteristics, higher WMC individuals additionally activate and use deeper, more relational, knowledge. This suggestion is consistent with studies on domain knowledge expertise and problem solving performance (Chi, Feltovich & Glaser, 1981). While the ability to activate and use more information can be generally useful when occurring in the appropriate context, an interesting caveat to this assertion is that these high WMC individuals may inadvertently activate more information than is necessary, due to this more clustered search. For example, not all information is directly relevant, and this overzealous retrieval could thereby increase the raw probability that task-irrelevant information *could* need to be suppressed by the executive system in WMC. Furthermore, there is some indication that high WMC individuals are less likely to engage in suppression of their own retrieved knowledge, specifically when the individual approaches a high level of knowledge in a given topic (Beilock & DeCaro, 2007; Ricks, Turley-Ames & Wiley, 2007).

In sum, there is a strong suggestion that differences in WMC should affect the susceptibility of individuals to bias in perceptual judgments as a result of prior knowledge. However, this interaction may be influenced by characteristics of participants' own knowledge base, and their own confidence in this knowledge. To test whether this is indeed the case, individuals who differed in WMC were examined for perceptual bias in three experiments. In all experiments, individuals high and low in WMC were evaluated on their ability to make physical size judgments when potentially biasing information was present at the time of judgment. If higher WMC does reliably translate into a more appropriate application of prior knowledge, one might expect that those higher in WMC should be less susceptible to biases in size judgment as they should be able to better control this automatic application of potentially irrelevant information. If this is not the case, alternative explanations centered around the interaction of WMC and retrieval from LTM must be considered.

Experiment 1

Method

Participants

Forty-four undergraduates from an Introductory Psychology course at a large public university were solicited for participation. Twenty-two participants were low in WMC (63 % female, average age = 20.81 years (standard deviation [SD] = 5.20)) as determined by WMC prescreening (see below), and the remaining 22 participants were high in WMC (59 % female, average age = 20.50 years (SD = 3.49)). All participants were Native English speaking right-handers with normal vision and also reported that they had played either mini-golf or golf in the past. All participants were compensated with course credit.

Materials

Working memory capacity prescreening As part of a larger effort, participants completed the Symmetry Span (SSpan) task (Unsworth et al., 2009) in a separate session. In this task, participants are asked to make judgments about whether a given image is symmetrical along a vertical axis (yes/no) and then are shown a location in a 4 × 4 matrix to remember for later test. Trials are grouped into sets of two to five trials, and participants completed three instances of each set size. After each set, participants are asked to recall the matrix locations for all preceding trials, in correct serial order. A single point is awarded for every trial recalled. The maximum score on this measure is 42.

Based on this larger prescreening (N = 165), participants who fell in the upper and lower 1/3 of the overall distribution were solicited for participation in this experiment. As expected, the average SSpan score of the low WMC group used in this study ($M = 23.05$, $SD = 3.21$) was significantly lower than the SSpan score of the high WMC group ($M = 34.59$, $SD = 3.32$; $F(1, 42) = 137.38$, $MSe = 10.67$, $p < 0.01$, $\eta^2_p = 0.77$), confirming this group dichotomy.

Demographic survey The Demographic Survey asked participants to report several simple demographic variables including age, sex, handedness, whether or not they had every played golf/mini-golf, had normal vision, and were a Native English speaker.

Size judgment task The Size Judgment Task is comprised of three distinct subsets that were all presented by computer to participants in the same order. In the Baseline portion of the task, participants were shown one of four rectangles of various widths (33 mm, 51 mm, 65 mm, and 83 mm) for 10 seconds and asked to recall the width of this rectangle. This rectangle was solid white in color and presented against a dark green shaded background to maintain a high level of contrast. Before recalling the width of the rectangle, participants completed a filler task for 15 seconds that involved the completion of simple algebraic problems (e.g., (9 + 3) x 5 = ?). This math problem task was designed to eliminate the ability of participants to rehearse and thus maintain the rectangle in STM. This was to ensure that any subsequent pattern of results was due to the influencing of biasing information on representation, and not merely differences in the ability to maintain information active in STM for a short period of time. In other words, while it is entirely possible that maintenance of information in STM might impact size judgments, it was desirable to eliminate it as a mitigating factor in the current investigation as that was not the focus of this study.

To recall the width of each rectangle, participants were given a horizontal line of length 135 mm, on which there was an anchor point represented by a single vertical line at the left end of the line. Participants were instructed to mark on this horizontal line, using another single vertical line, where the right side of the rectangle would be, if the left side of the rectangle was placed on the other vertical line (e.g., the left end of the horizontal line). Participants were instructed to recall the exact size of the rectangle as it appeared on screen. This method allowed participants to recall what they perceived to be the actual size of the shape, without forcing them to translate the rectangle into some other unit of measurement, standardized or not. After completing the size estimation, participants were then asked to provide a confidence rating for the correctness of this size judgment on scale of 1-8, with 8 being the most confident. Participants then repeated this procedure for the remaining baseline rectangles, until they had rated/viewed all four rectangles. Importantly, the 4 widths chosen for these Baseline rectangles represent 2 standard differences (7 mm and 25 mm) above and below the Target shape described below. Also, all rectangles were of the same height (33 mm), and the order of presentation of the four rectangles was randomized by participant in this Baseline portion.

After completing the Baseline portion of the SJT, participants then completed the Memory trial. In the Memory trial, for 10 seconds participants were instead shown a screen that just contained the background from the Baseline trials but were now asked to imagine a real golf ball floating on the screen. After the 10 seconds were up, participants then completed math problems for 15 seconds, after which they produced a size and confidence rating judgment as before. This portion of the SJT was designed to evaluate participants' LTM representation of the potentially biasing information (e.g., a golf ball). In other words, it is critical to establish that the LTM trace of the potentially biasing information is in fact equivalent across groups. If not, this could represent a potential confound relative to the magnitude of the biasing effect of prior knowledge.

Finally, after completing the Memory trial, participants then completed the Target trial. Before viewing this shape, participants were instructed that they would see a shape on the screen that was in fact a golf ball; however, this shape *may or may not* be the actual size of a real golf ball. In other words, participants were explicitly informed that the shape to-be-presented could be different from the size of an actual golf ball. This ambiguous instruction served two critical purposes. First, and perhaps most importantly, it was designed to dissuade individuals from simply recalling their LTM representation of a golf ball in response to the size estimation prompt. Furthermore, it enabled learners to simultaneously and critically evaluate their estimate of the size of the presented ball in the context of their prior knowledge. In other words, participants were completely justified in making a comparison to prior knowledge if they chose to. Similarly, if participants chose to actively inhibit any relation to prior knowledge, this also was implicitly permitted. It is the contention here that this comparison to prior knowledge is fundamentally connected to differences in WMC.

Participants also were instructed that all visual detail had been removed from the picture, so the shape would simply appear as a white circle, analogous to the rectangles they had seen before. This solid white presentation was utilized to avoid any potential confounds of visual features related to an actual image of a golf ball interacting with the size judgment (i.e., shadows, dimples, etc.). The removal of detail is also important as it ensures that the target object itself would not overwhelm the visual WMC of either group, and thus was equally accessible to both high and low WMC individuals. The actual shape was presented with a diameter of 58 mm, which is approximately 15 mm larger than a standard golf ball. This slightly larger presentation was designed to allow participants to apply their prior knowledge regarding the size of the golf ball, without technically violating the actual size of a real golf ball, and thus enable them to produce a judgment smaller than the actual presentation, yet still consistent with a representation of the real object. After viewing the target shape, participants again did math problems, after which they were explicitly asked to produce a size and confidence judgment for the shape they had seen on the screen.

Each subset of the SJT was scored as follows. For the Baseline trials, the actual size of each respective shape (in mm) was subtracted from participants' size estimation. Thus, a positive number indicates that participants overestimated the size of the shape, whereas a negative number would indicate a tendency to underestimate the size of the shape. The inaccuracy of these four trials was then averaged together to produce an average inaccuracy for size estimation in the absence of biasing information. For the Memory trial, the length (in mm) of the size estimation was used. As such, larger numbers indicate larger representations of the size of a golf ball. Finally, the Target trial was scored identically to the Baseline trials, and a negative score would again indicate an underestimation of size, while a positive score would indicate overestimation. Example stimuli for the Baseline and Target trials are available in Fig. 1.

Procedure

After completing informed consent, participants first completed the SJT. After completing the SJT, participants then completed the Demographic Survey. This order was intentional to avoid any potential bias that might be produced by questions on the Demographic Survey. This portion of the experiment

Fig. 1 Example stimuli for the baseline (left) and target (right) trials used in both experiments

took no longer than 30 min. Participants completed the SSpan task in a separate 30-min session.

Results and discussion

Unless otherwise noted, low and high WMC groups were compared with simple between-groups ANOVAs, and all results were evaluated at $p < 0.05$ for significance. Levene's tests for all analyses also indicated that variances were equivalent across samples and comparisons ($p > 0.05$).

Math problem accuracy

On the math filler task that took place between all trials and size judgments there was found to be no difference (*F*s < 1) in either the number of problems attempted between high (*M* = 18.32, SD = 5.45) and low (*M* = 17.36, SD = 4.81) WMC individuals, nor proportion of problems solved correctly between high (*M* = 0.92, SD = 0.08) and low (*M* = 0.90, SD = 0.06) WMC individuals. This suggests that this filler task was approached in similar ways by both WMC groups and not unduly ignored or dismissed by one group versus the other. Furthermore, the overall high level of correct performance by both groups (e.g., >90 %) suggests that both groups also took this filler task seriously.

Baseline trials

On the baseline trials, on average there was found to be no reliable difference between the low (*M* = −10.07 mm, SD = 7.69) and high WMC (*M* = −12.63 mm, SD = 10.30) groups in the inaccuracy of estimating the size of the baseline rectangles ($F(1, 42) = 0.88$, $MSe = 82.56$, $p > 0.05$). Low (*M* = 5.76, SD = 0.88) and high (*M*=6.01, *SD*=.57) WMC individuals also did not significantly differ in their confidence ratings relative to these size judgments ($F(1, 42) = 1.24$, $MSe = 0.55$, $p > 0.05$). This suggests that both low and high WMC individuals are equally adept at not only estimating the size of a visual object, but are also similar in respect to the subsequent confidence rating of this generic size judgment.

Memory trial

In the memory trial, participants were shown a blank screen and asked to imagine a real golf ball on the screen. There was again found to be no difference between the WMC groups in terms of size estimation ($F(1, 42) = 0.27$, $MSe = 109.78$, $p > 0.05$). This suggests that the LTM representation of the size of a golf ball was functionally equivalent between the low (*M* = 39.19 mm, SD = 6.20) and high (*M* = 37.55 mm. SD = 13.46) WMC groups. This finding is especially important, because it suggests that both WMC groups have a similar representation of the size of a golf ball, and any subsequent effects cannot be due to differences between the groups in how large they remember a golf ball to be.

However, there was a significant difference when comparing the confidence ratings of the WMC groups in this memory trace ($F(1, 42) = 7.55$, $MSe = 1.73$, $p < 0.01$, $\eta^2_p = 0.15$). High WMC individuals were significantly *more* confident in the accuracy of their size estimate (*M* = 6.59, SD = 0.80) than low WMC individuals (*M* = 5.50, SD = 1.68).

Target trial

In terms of the critical target trial, where participants were told that the subsequent circle was in fact a golf ball before viewing, a between-groups ANCOVA was conducted using baseline inaccuracy as a covariate in an effort to control for any individual biases in size estimation. Results indicated that baseline inaccuracy was a significant covariate predictor ($F(1, 41) = 13.55$, $MSe = 46.75$, $p < 0.01$, $\eta^2_p = 0.25$); however, more importantly there was a significant difference in size estimation between WMC groups ($F(1, 41) = 15.43$, $MSe = 46.75$, $p < 0.01$, $\eta^2_p = 0.27$). High WMC individuals were actually *more* likely to underestimate the size of the shape (*M* = −6.31 mm, SD = 6.85) than low WMC individuals (*M* = 1.86 mm, SD = 6.85). Only the size estimate from the high WMC group was significantly different from zero ($t(21) = 4.32$, $p < 0.01$).

This bias in underestimating the size of the shape was accompanied by a significant increase in confidence ratings in the high WMC group ($F(1, 41) = 10.42$, $MSe = 1.42$, $p < 0.01$, $\eta^2_p = 0.20$), as evaluated by a between-groups ANCOVA using baseline confidence ratings as a covariate ($F(1, 41) = 5.30$, $MSe = 1.42$, $p < 0.01$, $\eta^2_p = 0.11$) to again control for any individual biases in confidence judgments. This suggests that despite underestimating the size of the ball, high WMC individuals ($M = 6.66$, SD = 1.20) were *more* confident in the accuracy of their size judgments versus low WMC individuals ($M = 5.48$, SD = 1.20). Could it be that this overconfidence is directly related to the observed bias in the high WMC group?

To better explore this potential connection, a final analysis was done relating these confidence ratings to the perceived size of the observed shape. A hierarchical linear regression was conducted to predict size estimation. In the first block, participants' confidence in their size rating, and WMC group were entered simultaneously, and then in the second block an interaction term between WMC group and confidence rating was entered. This procedure allows an assessment of whether confidence ratings and size estimation were differentially related across the WMC groups. Results from the first block of analysis ($R^2 = 0.28$; $F(2, 41) = 8.03$, $p < 0.01$) indicated that while overall WMC group did significantly predict size estimation ($\beta = 0.46$, $p < 0.01$), confidence ratings did not ($\beta = 0.12$, $p > 0.05$). However, and most importantly, when adding the interaction term between WMC group and confidence ratings in the second block, the model was again significant ($R^2 = 0.35$; $F(1, 40) = 7.05$, $p < 0.01$), and predicted a significantly larger portion of variance in size estimation ($R^2\ \Delta = 0.06$, $p < 0.05$). In other words, it appears that confidence ratings are differentially related to size estimation across the WMC groups ($\beta = 1.72$, $p < 0.05$). This pattern is consistent with the simple correlations across WMC groups, which indicate a significant positive relationship between confidence judgments and size estimation in the high WMC group ($r = 0.42$, $p < 0.05$), but little relationship between these variables in the low WMC group ($r = -0.05$, $p > 0.05$) across the target trial.

In summary, there appears to be no difference between high and low WMC individuals when it comes to estimating the size of objects in the absence of biasing prior knowledge, as evidenced by the lack of difference in inaccuracy between groups on the baseline trials. There does also not appear to be a significant difference between the mental representations of the size of a golf ball between high and low WMC groups, although high WMC individuals tend to be more confident in the accuracy of said representation. Finally, when primed that a circle is a golf ball before viewing (even though participants were warned that it may not be the actual size of a real ball, thus providing an opportunity for explicit inhibition), only high WMC individuals were influenced by this conceptual prime and thus became susceptible to the biasing influence of prior knowledge.

Interestingly, despite the presence of this bias, high WMC individuals were significantly *more* confident that their size estimation was accurate versus their low WMC counterparts. As demonstrated in both the memory and target trials, when there appears to be a need to retrieve information from LTM, high WMC individuals are more confident that this retrieved information is accurate. While speculative, it is perhaps this overconfidence that is underlying high WMC individuals' failure to inhibit this information at the time of recall, thus producing this error in size judgment. Results of the final regression analysis seem to support this idea that confidence ratings and size estimations are more closely related in the high WMC group.

To confirm that this pattern of results is not an indirect result of the instructions themselves, and in fact due to an interaction with prior knowledge, a second experiment was conducted which utilized the exact same stimuli as Experiment 1 but gave different priming instructions on the target trial. These revised instructions should cause individuals to now *overestimate* the size of the target shape, assuming that this pattern of results is a direct result of an interaction with existing knowledge and confidence levels.

Experiment 2

Participants

Twenty high (55 % female, average age = 20.78 years (SD = 3.49)) and 18 low (56 % female, average age = 20.50 years (SD = 2.74)) participants, identified in the same fashion as in Experiment 1, but who had also not participated in Experiment 1, were solicited for participation in this second experiment. All participants were again undergraduates from an Introductory Psychology course at a large public university and were Native English speaking right-handers with normal vision. All participants were compensated with course credit, and reported they had played baseball, or thrown a baseball, previously (see below).

Materials and procedure

All materials and procedures was identical to Experiment 1, with one critical exception. On the Memory Trial and Target Trial of the Size Estimation Task, rather than being told to either imagine a real golf ball, or the target was a golf ball (e.g., Experiment 1), participants were instead instructed to imagine a real baseball on the screen or that the shape was a baseball. The stimulus itself, however, was unchanged. This adjustment is important, because a real baseball is in fact ~16 mm *larger* than the Target shape. This should produce an overestimation of size of the target shape, consistent with this fact. It is worth mentioning that this size difference between a real baseball and target shape is roughly equivalent to the size difference between a real golf ball and target shape, albeit in the opposite direction. Again, if the pattern of results in Experiment 1 is due to an activation of prior knowledge, this simple methodological change should now produce a similar magnitude of difference, but instead in the opposite direction (overestimation), consistent with the biasing information. All other aspects of the methodology were consistent across Experiments 1 and 2.

Results and discussion

As before, unless otherwise noted, low and high WMC groups were compared with simple between-groups ANOVAs, and all results were evaluated at $p < 0.05$ for significance. Levene's tests for all analyses also indicated that variances were equivalent across samples and comparisons ($p > 0.05$).

Math problem accuracy

On the math filler task that took place between all trials and size judgments, there was found to be no difference (Fs < 1) in either the number of problems attempted between high (M = 17.40, SD = 6.00) and low (M = 16.39, SD = 4.95) WMC individuals, nor proportion of problems solved correctly between high (M = 0.93, SD = 0.08) and low (M = 0.90, SD = 0.11) WMC individuals.

Baseline trials

On the baseline trials, again there was found to be no reliable difference between the low (M = −12.21 mm, SD = 2.71) and high WMC (M = −12.21 mm, SD = 2.64) groups in the inaccuracy of estimating the size of the baseline rectangles ($F(1, 36) = 0.00$, MSe =7.15, $p > 0.05$). Low (M = 5.72, SD = 0.97) and high (M = 6.01, SD = 0.60) WMC individuals also did not significantly differ in their confidence ratings relative to these size judgments ($F(1, 36) = 1.27$, MSe = 0.63, $p > 0.05$).

Memory trial

In the memory trial, where participants were shown a blank screen and now asked to imagine a real baseball on the screen, there was again found to be no difference between the WMC groups in terms of size estimation ($F(1, 36) = 1.09$, MSe = 162.20, $p > 0.05$). Once again, this suggests that the LTM representation of the size of a baseball was functionally equivalent between the low (M = 76.83 mm, SD = 14.95) and high (M = 81.15 mm, SD = 10.36) WMC groups. However, there also was again a significant difference when comparing the confidence ratings of the WMC groups in this memory trace ($F(1, 36) = 4.10$, MSe = 1.99, $p < 0.05$, $\eta^2_p = 0.10$). High WMC individuals were significantly *more* confident in the accuracy of their size estimate (M = 6.15, SD = 1.18) than low WMC individuals (M = 5.22, SD = 1.63).

Target trial

In terms of the critical target trial, a between-groups ANCOVA was again conducted using baseline inaccuracy as a covariate. Baseline inaccuracy was a significant covariate predictor ($F(1, 35) = 6.13$, MSe = 41.871, $p < 0.05$, η^2_p = 0.15); however, more importantly, just as in Experiment 1 there was a significant difference in size estimation between WMC groups ($F(1, 35) = 13.17$, MSe = 41.87, $p < 0.01$, η^2_p = 0.27). High WMC individuals were now more likely to overestimate the size of the shape (M = 8.30 mm, SD = 5.73) than low WMC individuals (M = 0.67 mm, SD = 8.04). Importantly, only the high WMC individuals' size estimation was significantly different from zero ($t(19) = 6.48$, $p < 0.01$).

Just as in Experiment 1, this bias in overestimating the size of the shape also was accompanied by a significant increase in confidence ratings in the high WMC group ($F(1, 35) = 4.75$, MSe = 89, $p < 0.05$, $\eta^2_p = 0.12$), as evaluated by a between-groups ANCOVA using baseline confidence ratings as a covariate ($F(1, 35) = 22.51$, MSe = 0.89, $p < 0.01$, $\eta^2_p = 0.39$). This suggests that once again, despite being less accurate at the target size estimation task, high WMC individuals (M = 5.95, SD = 1.05) were *more* confident in these judgments versus low WMC individuals (M = 5.00, SD = 1.33). Thus, consistent with the biasing influence of prior knowledge, high WMC individuals once again appear not only more susceptible to misestimations of size but also appear more erroneously confident in these judgments.

As in Experiment 1, a final analysis was done relating these confidence ratings to the perceived size of the observed shape. A hierarchical linear regression was conducted to predict size estimation. In the first block, participants' confidence in their size rating, and WMC group were entered simultaneously, and then in the second block an interaction term between WMC group and confidence rating was entered. This procedure allows an assessment of whether confidence ratings and size estimation were differentially related across the WMC groups. Results from the first block of analysis ($R^2 = 0.25$; $F(2, 35) = 5.73$, $p < 0.01$) indicated that while overall WMC group did significantly predict size estimation ($\beta = 0.47$, $p < 0.01$), confidence ratings did not ($\beta = 0.07$, $p > 0.05$). However, and most importantly, when adding the interaction term between WMC group and confidence ratings in the second block, the model was again significant ($R^2 = 0.33$; $F(1, 34) = 5.61$, $p < 0.01$), and predicted a significantly large additional portion of variance in size estimation ($R^2 \Delta = 0.08$, $p < 0.05$). In other words, it appears that confidence ratings are differentially related to size estimation across the WMC groups ($\beta = 1.61$, $p < 0.05$). This pattern is once again consistent with the simple correlations across WMC groups which indicate a significant positive relationship between confidence judgments and size estimation in the high WMC group ($r = 0.47$, $p < 0.05$), but little relationship between these variables in the low WMC group ($r = -0.20$, $p > 0.05$) across the target trial.

This same pattern of results (e.g., lower performance but higher confidence of high WMC individuals), now found across two experiments, is consistent with prior research that has shown that high WMC individuals do fail to inhibit irrelevant or competing information when this interference is a result of their own high domain knowledge (Ricks et al., 2007). In Ricks et al. (2007), high domain knowledge participants who also were high in WMC were less likely to exhibit their typical WMC advantage when it was required to suppress their domain knowledge in the remote associates task. However, low knowledge (but high in WMC) individuals were able to successfully inhibit the irrelevant mental set. In other words, this suggests that when there exists a strong mental trace derived from LTM, higher WMC individuals are *less* likely to inhibit such information for some reason, perhaps due to the overconfidence found here. This is consistent with problem-solving research that has found that high WMC individuals are more susceptible to induced mental sets when engaging in problem-solving behavior (Beilock & DeCaro, 2007). Again, high WMC individuals appear less likely to suppress what they perceive to be relevant prior knowledge, and this failure naturally degrades performance. This blind persistence, whether due to overconfidence or not, thus negatively affects performance solely in the high WMC group.

While failure to inhibit prior knowledge could be the explanation for performance of the high WMC group, why were those individuals lower in WMC not also susceptible to the perceptual bias? A tentative explanation is that low WMC individuals were less sensitive to the biasing information, because they had lost access to these biasing cues in primary memory at the time of judgment. As participants were required to complete a math filler task between the presentation and subsequent recall, it is entirely possible that during this time it was lost from STM and thus was not able to influence judgment at the time of retrieval. To truly understand whether this is in fact the case, it would be necessary to adjust the methodology to increase the likelihood that the biasing information is available at the time of test.

To evaluate these potential explanations, a third experiment was conducted to ensure that the cue was available at the time of retrieval for all participants, but also eliminate the need to draw information from LTM (and thus eliminate the overconfidence of the high WMC group), which would hopefully allow high WMC individuals to better demonstrate a resistance to the biasing information.

Experiment 3

A third experiment was conducted which modified the procedure used in Experiment 1. In this experiment, participants were not required to retrieve the mental representation of a golf ball from LTM in the target task, and the prime for golf ball was instead limited to STM alone.

Method

Participants

Thirty-six undergraduates who had not participated in Experiments 1 or 2 were solicited for participation. Again, based on WMC prescreening, 17 low WMC (65 % female, average age = 22.41 (SD = 5.71)) and 19 high WMC (68 % female, average age = 20.37 (SD = 3.79)) participants were successfully recruited. All participants were again Native English speaking right handers and reported having played golf or mini-golf at some point. Participants were compensated with course credit.

Materials and procedure

Materials and procedure were identical to Experiment 1, except for two key changes to the Size Judgment Task. First, the Memory trial was removed from the procedure to avoid providing a conceptual prime that might influence the Target trial. Second, the nature of the Target trial was changed to eliminate any need to retrieve a mental representation from secondary memory. Rather than being told they would be viewing a golf ball, participants were instead instructed that they would be a viewing "a ball that is used to play a specific sport, which may or may not be the actual size of the actual ball." Participants were given no other detail regarding the shape prior to viewing. After viewing the target image as before, rather than completing math problems, participants were instead directed to a small box next to their computer which they were told contained the ball that was used to create the image. A single golf ball was contained within the box. Participants were given 15 seconds to visually inspect the ball but were not allowed to physically touch or otherwise interact with the ball. As such, it was not necessary to retrieve the mental trace of "golf ball" in this experiment from LTM; instead, the golf ball existed solely as a trace within STM, specific to the ball that they had just viewed. After 15 seconds, participants were instructed to close the box and then recall the size of the "ball" presented on the screen (not the ball they had just seen in the box) and make a confidence judgment as before. All other trials within this second experiment were identical to Experiments 1 and 2.

Results and discussion

As in Experiments 1 and 2, data were analyzed using a simple between groups ANOVA unless otherwise noted, and evaluated for significance at $p < 0.05$. Levene's tests for all analyses also indicated that variances were equivalent across samples and comparisons ($p > 0.05$).

Math problem accuracy

On the math filler task that took place between all trials and size judgments there was found to be no difference ($F < 1$) in the number of problems attempted between high ($M = 13.42$, SD = 4.22) and low ($M = 12.13$, SD = 4.19) WMC individuals. However, there was a significant difference in the proportion of problems solved correctly between high ($M = 0.96$, SD = 0.06) and low ($M = 0.91$, SD = 0.09) WMC individuals ($F(1, 34) = 4.24$, $MSe = 0.01$, $p < 0.05$), driven by the very high achievement of the high WMC group. However, as both groups accuracy levels were >90 %, this difference is not indicative of the task being ignored by or not taken seriously by the low WMC group, and thus served its purpose as an adequate distractor task.

Baseline trials

As in previous experiments, there was again no reliable difference between the low ($M = -10.60$ mm, SD = 6.98) and high WMC ($M = -8.17$ mm, SD = 6.29) groups ($F(1, 34) = 1.21$, $MSe = 43.91$, $p > 0.05$) when it came to the inaccuracy of estimating the size of the baseline rectangles. Low ($M = 5.50$, SD = 1.05) and high ($M = 5.68$, SD = 0.81) WMC individuals again did not significantly differ in their confidence ratings relative to these size judgments ($F(1, 34) = 0.35$, $MSe = 0.86$, $p > 0.05$). These results suggest that low and high WMC individuals are equivalent in the ability to estimate the size of a visual object and are once again similar in the subsequent confidence rating of this judgment, consistent with both previous experiments.

Target trial

In terms of the critical target trial, where participants were not told that the subsequent circle was in fact a golf ball until after viewing it, a between-groups ANCOVA was conducted using baseline inaccuracy as a covariate. Again, there was a significant difference in the inaccuracy of the size estimation of the ball between WMC groups ($F(1, 33) = 5.11$, $MSe = 65.21$, $p < 0.05$, $\eta^2_p = 0.13$). However, the pattern of results was directly opposite that of Experiment 1. In this experiment, low WMC individuals were less accurate ($M = -6.47$ mm, SD = 8.15) than high WMC individuals ($M = -0.27$ mm, SD = 8.14). In this experiment, only the low WMC individuals' size estimation was now significantly different from zero ($t(16) = 3.27$, $p < 0.01$). Low WMC individuals significantly underestimated the size of the circle, whereas high WM individuals did not.

Again contrary to Experiment 1, there also was now no difference between WMC groups in terms of their confidence of the size judgment, ($F(1, 33) = 0.01$, $MSe = 1.37$, $p > 0.05$), as evaluated by a between-groups ANCOVA using baseline confidence ratings as a covariate. High WMC individuals ($M = 5.30$, SD = 1.18) were as confident in the accuracy of their judgments as low WM individuals ($M = 5.26$, SD = 1.18) on the target trial.

Finally, a hierarchical linear regression was again conducted using confidence ratings to predict size estimation for the target trial. Again, confidence ratings and WMC group were entered in the first block, and an interaction term between WMC group and confidence ratings was then entered in the second block to test for a differential relationship between confidence ratings and size estimation across the WMC groups. Results indicated that WMC group did significantly predict size estimation ($\beta = -0.39$, $p < 0.05$; $R^2 = 0.14$; $F(2, 33) = 3.79$, $p < 0.05$), but overall confidence ratings did not ($\beta = -0.15$, $p > 0.05$). There also was no indication that the relationship between confidence ratings and size estimation was different across WMC groups ($R^2\ \Delta = 0.02$, $p > 0.05$).

This pattern of results sheds further light on the relationship between WMC and bias on perceptual judgment. While high and low WMC individuals are equivalent on their ability to judge size (and confidence in this judgment) when no biasing information is present, when biasing information is more likely present in STM, as originally expected, low WMC individuals are now more susceptible to making an error in judgment than high WMC. This reversal of results from Experiment 1 can be considered a direct result of eliminating the retrieval of the memory trace of "golf ball" from LTM. When a task contains such a requirement, it appears that high WMC individuals, perhaps due to overconfidence in the quality of this representation (see Experiments 1 and 2), appear to allow such information to inappropriately influence performance. This overconfidence appears to be specifically derived from the fact that information is retrieved from *their* LTM, rather than just a global confidence in their perceptual judgment (not observed in the Baseline trials). When this requirement is removed, as was the case here, high WMC individuals are better able to not allow such information to bias size judgment. Similarly, the temporal proximity of the biasing presentation and recall also better ensured that this cue was available at the time of recall for all participants. Again, as expected, low WMC individuals were less able to deal with this cue, thus producing the anticipated underestimation of size.

General discussion

The results of these experiments provide an interesting view on differences in WMC and how they might relate to the influence of potentially biasing information retrieved from LTM. While it was expected that high WMC individuals would be less susceptible to such influences, results of the first and second experiments produced the opposite, that in fact high WMC individuals were *more* likely to demonstrate an influence of prior knowledge on their perceptual judgment of size. As the raw ability to judge physical size, and the mental representation of the size of a golf ball or baseball, were equivalent across low and high WMC groups, these results were somewhat quizzical. An explanation for this pattern of results could be twofold. First, it is entirely possible that in low WMC individuals the conceptual prime had faded from STM by the time the perceptual judgment was made and thus was not able to subsequently bias the judgment. Secondly, and perhaps related to this notion of maintenance in STM, is the fact that high WMC individuals reported being significantly more confident in their size judgment, despite the fact that they were demonstrating the perceptual bias. Supporting this notion, a similar inflation in confidence was also demonstrated in the Memory trial where high WMC individuals were more confident in the accuracy of their mental representation of a golf ball/baseball than low WMC individuals. This suggests that for some reason high WMC individuals are more confident in the quality of information retrieved from their LTM. The effects of this overconfidence could cause high WMC individuals to more highly prioritize or weight this retrieved information, which would naturally result in a greater likelihood of maintaining it in STM so that it is available at the time of the size judgment. Another natural byproduct would be that this information would most definitely be seen as relevant for the task at hand, and thus permitted to influence the size judgment, again as a direct result of this overconfidence. Regression analyses seem to support these explanations, as high WMC individuals demonstrated a significantly positive relationship between confidence judgments and size estimation in the target trial, which was not observed in low WMC individuals. In order to explore these potential explanations further, a third experiment was conducted that was designed to better ensure that not only was the biasing information present in STM for low WMC individuals, but also eliminate the need of high WMC individuals to retrieve this information from LTM, and thus potentially overweigh it.

Results of the third experiment confirmed the originally hypothesized pattern of results; low WMC were now more likely to exhibit the perceptual bias, and high WMC individuals successfully ignored such biasing information and made an accurate judgment of physical size. Importantly, the overconfidence exhibited by high WMC individuals also was eliminated, as was the relationship between confidence ratings and size estimation in the high WMC group, lending further support to the notion that information retrieved from their own LTM is overvalued by high WMC individuals, and it is this overvaluation that leads to the demonstrated biases in Experiments 1 and 2.

This reversal of results highlights an interesting new caveat to the relationship between WMC and retrieval from LTM. It does appear that WMC does not only produce quantitative differences in the amount and type of information retrieved (Unsworth, Brewer & Spillers, 2013), but an additional byproduct is that because said information was retrieved from within, WMC also appears to be related to qualitative differences in one's attitude toward retrieved information. This is consistent with other research that has demonstrated that high WMC individuals who have high domain knowledge are less likely to suppress or inhibit knowledge relative to task performance, whereas low knowledge but high WMC individuals can (Ricks et al., 2007). This also could be seen as analogous to an effect of cue familiarity, which has been shown to increase feelings of knowing related to judgment (Reder, 1987). However, in this case, cue familiarity is not an explicit intralist referent, but instead a source cue that references that information was retrieved from what is normally a very reliable system or source: the high WMC participants' own long-term store. Because the cue is internally generated, it also is given a "pass" by the executive system, again likely because it is self-derived (Ricks et al., 2007). Just as expertise in a content area can lead to less optimal performance in other areas, it is this perceived general expertise or competency that then leads to the inappropriate influence of information on judgment. Thus, this suggests that the interaction between WMC and LTM is far from a simple linear process, and that when there exists a high level of both knowledge *and* WMC, what is normally an advantage can become a distinct disadvantage. This finding has implications not only for future work on perceptual biases, but also likely resonates through any work where it is possible that high WMC individuals concurrently possess high levels of domain knowledge.

Future efforts should further explore the explicit nature of this overconfidence in LTM across individuals. For example, an interesting question is what level of experience is required to reach such levels, where information ceases to be internally critiqued relevant to every application. Furthermore, it is of interest whether this experience needs be attached to a specific domain or whether a general conceptualization of the overall quality of the system (i.e., "I am a smart individual, my view of the world is generally correct.") is sufficient to produce such inaccuracies. Also, interactions with task instructions and how different instructions or descriptions of the task might impact the activation or usage of prior knowledge also are very interesting relative to the observed findings.

Additionally, it is of interest to explore how this overconfidence and perceptual bias might unfold across multiple trials or judgments. For example, is it possible that high WMC individuals might be able to negate or attenuate their bias with more opportunity? While the current study cannot directly speak to this question as no longitudinal component was included, it is speculated that this would likely not be the case for a few reasons. If higher WMC individuals were able to make themselves more accurate, it would seem reasonable to expect that their variances would be larger on the target trial, and later accuracy could be realized by shrinking this variance more closely around the actual correct response. Unfortunately, across all three experiments, variance estimates were largely identical between groups, which seem to contradict this notion. The buildup of proactive interference across such multiple estimates might also produce an additional negative side-effect on perception, as participants conflate their previous trials with the actual presented target. However, because there was again no data collected on this longitudinal aspect, this remains an open question and a subject for future research.

Finally, it would be interesting to examine how various levels of concurrent task load might exacerbate or attenuate the observed pattern of findings. While the current secondary task (math problems) did not appear to overload individuals, because this was not its methodological function, it would be interesting to explore how more demanding secondary task characteristics might impact the interaction between LTM and consciousness. Given that prior research has shown that concurrent task loads make higher WMC individuals functionally equivalent to lower WMC individuals in terms of cognitive performance (see Cowan et al., 2005 for a discussion), it is reasonable to expect that the addition of this task load might prohibit higher WMC individuals from using prior knowledge erroneously. This would allow for a more nuanced refinement of this effect and perhaps an opportunity to eliminate a disparity between these WMC groups. By better understanding the interaction between these cognitive systems, it may be possible to produce optimal performance in both perceptual and conceptual tasks for all individuals, by making individuals better aware of such interactions and how they subsequently impact performance.

References

Baddeley, A. D., & Hitch, G. (1974). Working memory. *Psychology of Learning and Motivation, 8,* 47–89.

Beilock, S. L., & DeCaro, M. S. (2007). From poor performance to success under stress: Working memory, strategy selection, and mathematical problem solving under pressure. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 983–998.

Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5,* 121–152.

Conway, A. R., Cowan, N., & Bunting, M. F. (2001). The cocktail party phenomenon revisited: The importance of working memory capacity. *Psychonomic Bulletin & Review, 8*(2), 331–335.

Cowan, N., Elliott, E. M., Scott Saults, J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology, 51*(1), 42–100.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450–466.

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review, 3*(4), 422–433.

Doherty, M. J., Campbell, N. M., Tsuji, H., & Phillips, W. A. (2010). The Ebbinghaus illusion deceives adults but not young children. *Developmental Science, 13*(5), 714–721.

Ellis, R. R., & Lederman, S. J. (1998). The golf-ball illusion: Evidence for top-down processing in weight perception. *Perception, 27*(2), 193–202.

Ericsson, K. A., Charness, N., Feltovich, P. J., & Hoffman, R. R. (Eds.). (2006). *The Cambridge handbook of expertise and expert performance*. Cambridge: Cambridge University Press.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102*(2), 211.

He, X., Zhang, W., Li, C., & Guo, C. (2015). Precision requirements do not affect the allocation of visual working memory capacity. *Brain Research, 1602,* 136–143.

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(2), 336–358.

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General, 132*(1), 47–70.

Keppel, G., & Underwood, B. J. (1962). Proactive inhibition in short-term retention of single items. *Journal of Verbal Learning and Verbal Behavior, 1*(3), 153–161.

Lien, M. C., Ruthruff, E., & Naylor, J. (2014). Attention capture while switching search strategies: Evidence for a breakdown in top-down attentional control. *Visual Cognition, 22,* 1105–1133.

Luchins, A. S. (1942). Mechanization in problem solving: The effect of Einstellung. *Psychological monographs, 54,* 1–95.

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature, 390,* 279–281.

Lustig, C., May, C. P., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General, 130*(2), 199–207.

McVay, J. C., & Kane, M. J. (2012). Why does working memory capacity predict variation in reading comprehension? On the influence of mind wandering and executive attention. *Journal of Experimental Psychology: General, 141*(2), 302.

Meyer, D. E., & Schvaneveldt, R. W. (1976). Meaning, memory structure, and mental processes. *Science, 192*(4234), 27–33.

Reder, L. M. (1987). Strategy selection in question answering. *Cognitive Psychology, 19*(1), 90–138.

Ricks, T. R., Turley-Ames, K. J., & Wiley, J. (2007). Effects of working memory capacity on mental set due to domain knowledge. *Memory & Cognition, 35*(6), 1456–1462.

Roggeman, C., Klingberg, T., Feenstra, H. E., Compte, A., & Almeida, R. (2014). Trade-off between capacity and precision in visuospatial working memory. *Journal of Cognitive Neuroscience, 26,* 211–222.

Schmader, T., & Johns, M. (2003). Converging evidence that stereotype threat reduces working memory capacity. *Journal of Personality and Social Psychology, 85*(3), 440.

Shelton, J. T., Elliott, E. M., Matthews, R. A., Hill, B. D., & Gouvier, W. D. (2010). The relationships of working memory, secondary memory, and general fluid intelligence: Working memory is special. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*(3), 813.

Unsworth, N., Brewer, G. A., & Spillers, G. J. (2013). Working memory capacity and retrieval from long-term memory: The role of controlled search. *Memory & Cognition, 41*(2), 242–254.

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*(1), 104–132.

Unsworth, N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage. *Memory, 17*(6), 635–654.

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*(6), 1302.

Wheeler, M. E., & Treisman, A. M. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology: General, 131,* 48–64.

Wiley, J. (1998). Expertise as mental set: The effects of domain knowledge in creative problem solving. *Memory & Cognition, 26*(4), 716–730.

Zhang, W., & Luck, S. J. (2011). The number and quality of representations in working memory. *Psychological Science, 22,* 1434–1441.