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Working memory and flexibility in awareness and attention

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Abstract We argue that attention and awareness form the basis of one type of working-memory storage. In contrast to models of working memory in which storage and retrieval occur effortlessly, we document that an attention-demanding goal conflict within a retrieval cue impairs recall from working memory. In a conceptual span task, semantic and color-name cues prompted recall of four consecutive words from a twelve-word list. The first-four, middle-four, and final-four words belonged to different semantic categories (e.g., body parts, animals, and tools) and were shown in different colors (e.g., red, blue, and green). In Experiment 1, the color of the cue matched that of cued items 75% of the time, and the rare mismatch impaired recall. In Experiment 2, though, the color of the cue matched that of the cued items only 25% of the time, and the now-more-frequent mismatches no longer mattered. These results are difficult to explain with passive storage alone and indicate that a processing difficulty impedes recall from working memory, presumably by distracting attention away from its storage function.

Introduction

What is the relation between immediate memory and conscious awareness? James (1890) described *primary memory* as "the trailing edge of the conscious present." (Related statements by an early experimental psychologist, Wilhelm Wundt, apparently were never translated into English and would be better described by a German psychologist.) Whereas the trailing-edge description might leave the impression that primary memory serves no important purpose in behavior, in a slight re-conceptualization it can be equated with *working memory*, the small amount of information that is readily accessible (in contrast to the vast storehouse of long-term memory, which can be accessed only slowly and less surely). Working memory acquired its name because it presumably serves the important function of making available the data needed to carry out cognitive tasks such as comprehension, linguistic planning, and problem-solving (Baddeley, 1986; Baddeley & Logie, 1999). Combining James' description with more recent work, the information readily accessible to the human mind may have both experiential and behavioral facets.

It cannot be assumed, though, that the mechanisms of working-memory storage and the contents of conscious awareness are one and the same. To the extent that storage is accomplished through a general mechanism that can be shared between disparate types of information and is limited in its capacity (e.g., Atkinson & Shiffrin, 1968), it is the kind of storage mechanism that presumably could qualify as the contents of awareness (Baars, 1988, 2001; Cowan, 1988, 1995, 1999, 2001). However, theoretical descriptions of working memory also have included mechanisms that do not fit this description. Proposed mechanisms of this sort have included a large-capacity, short-lived sensory memory (e.g., Broadbent, 1958; Cowan, 1995), code-specific phonological and visuo-spatial buffers (e.g., Baddeley & Logie, 1999), and activated features drawn from long-term memory (e.g., Cowan, 1995; Norman, 1968). These mechanisms have been assumed to lose information through decay and/or through interference from other stimuli with similar features, but they are not limited in capacity per se. Moreover, information in these mechanisms is said to be automatically held, not subject to loss through general distraction (although this is an ideal based on the assumption that the information automatically held does not share stimulus features with the information serving as the distraction).

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The evidence for some sort of passively-held information storage devices seems strong, whereas the evidence for a general, attention-dependent form of storage is more controversial. An alternative possibility is that a central attention-and-awareness mechanism is able to operate using only the information held in passive buffers.

A slightly more moderate alternative is that central attention contains only information about the ongoing task goals, and must rely on passive storage devices to hold the rest of the information. In this regard, several recent studies have shown that individuals with high versus low memory span differ in how well they are able to hold on to a task goal in the presence of competing pressures on behavior. For example, Kane, Bleckley, Conway, and Engle (2001) showed that individuals with low working-memory span have difficulty with an "antisaccade" task in which they are to act counter to the natural tendency, moving their eyes away from, rather than toward, a suddenly-appearing target. Conway, Cowan, and Bunting (2001) showed that individuals with low working-memory spans are much more likely than high-span individuals to hear their own names in the irrelevant channel (the left ear's message) in a selective listening task with shadowing of the relevant channel. The proportion of name detection was 65% for the lowest quartile of working memory, versus only 20% for the highest quartile.

This research leaves open the role of attention in holding on to other information in working memory. Cowan (2001) suggested that it is necessary to attend to several objects at once if the individual needs to compare them with one another or integrate them, and reviewed a great deal of evidence that adult humans have a fundamental capacity limit of about four objects or chunks of information on average, individually varying from as low as two to as high as six. It was suggested that this fundamental capacity limit may reflect the limit in the contents of the focus of attention. The better-known limit of about seven items (Miller, 1956) may occur because items are being rapidly grouped together to form a smaller number of independent chunks, or because they are held with the benefit of rehearsal in effortlessly-held phonological storage. Cowan (2001) proposed that a fundamental limit of about four items is observed when the rehearsal and grouping of these items are somehow prevented. It was further proposed that the focus of attention is the holding device for this limited amount of information. This information can take the form of a simultaneous array or of a sequence of items, in either case transferred from relatively unanalyzed, passive forms of storage into the focus of attention, where it can receive more perceptual and conceptual analysis.

Baddeley (2000) recognized that the phonological and visuo-spatial mechanisms that he previously proposed for information storage were insufficient to account for all types of temporary storage. Therefore, he proposed a new, *episodic buffer* mechanism, which presumably holds semantic and abstract types of information. Baddeley (2001) further suggested that the episodic buffer may be capacity-limited. To our knowledge, he has not made it clear whether maintenance of information in this episodic buffer is supposed to be attention-demanding or attention-free.

Our current view was articulated by Cowan (2005). It states that a participant's attention is flexible in its allocation and that it can *zoom in* to hold on to a task goal in the face of interference, *zoom out* to apprehend a field of up to about four objects or chunks of information that are independent from one another from the participant's point of view (or can hold more information if there are associations between items; see Hulme, Stuart, Brown, & Morin, 2003). It presumably also can adopt some intermediate scope, with the capability of apprehending fewer than four items in order to allocate some attention to goal maintenance concurrently. A central prediction of such a view is that there should be trade-offs between the goal-maintenance and information-apprehension functions of the focus of attention.

According to the version of working-memory theory that has been applied most often to the investigation of individual and developmental differences, the allocation of a central space must be divided between the storage and processing of information (Case, Kurland, & Goldberg, 1982; Daneman & Carpenter, 1980). There have been mixed reports on whether concurrent processing and storage of information in fact trade off (e.g., Barrouillet, Bernardin, & Camos, 2004) or not (e.g., Duff & Logie, 2001).

To examine a type of processing that causes a goal conflict, in two experiments, we made use of the well-known color-word interference effect first reported by Stroop (1935), in which the color of a printed word is to be named quickly and is found to be especially difficult to name if it forms a conflicting color name. Two recent studies have shown that this task is sometimes carried out more successfully by individuals with high memory-span scores than by individuals with low-span scores (Long & Prat, 2002; Kane & Engle, 2003). However, this span difference depended on the sequence of trials. When the session included a large majority of trials in which the word and the color matched (e.g., the word *red* printed in red), then it was especially difficult to keep in mind that the word occasionally could be misleading (e.g., the word *blue* printed in green). Under such circumstances, high-span individuals excelled. If the session included relatively few trials in which the word and color matched, it was easier to keep in mind the goal of the task and there was less difference between high-span and low-span individuals.

According to the notion that the focus of attention must expand to hold onto a set of items or contract to hold onto a goal in the face of adversity (Cowan, 2005), there should be a cost of requiring both at once. One way to test this would be to impose a goal conflict such as color–word interference during the reception of items to be recalled. However, this might demonstrate a conflict between encoding and processing, not necessarily between storage and processing. Instead, we imposed a conflict between the color of a word at the time of encoding and the color of the word used as a retrieval cue. We did so in a working-memory task that is not very susceptible to phonological rehearsal and grouping, the clustered categories version of Haarmann, Davelaar, and Usher's (2003) conceptual span task. In their task, items from multiple semantic categories (e.g., animals, jobs, clothes) are presented sequentially, and a semantic category cue prompts recall of the items from just one category. For example, if given the items and cue, "lamp, fax, phone, pear, apple, grape, tiger, elephant, horse, FRUIT," the correct answer would be, "pear, apple, grape." When this task was adapted for use in the current Experiment 1, the memoranda were also shown in color, and color-name cues were added in half of the trials. For example, if given the cue, "RED," participants were to recall all of the words from the current trial that were shown in the color red (which were all of the words from one particular semantic category).

The color of the semantic category cues was manipulated to create the potential for distraction. Cue color and list-item color matched in the majority of semantically-cued trials, and in all trials with color-name cues. However, there was an occasional mismatch between cue color and list-item color in some semantically-cued trials. The design of our Experiment 1, a modification of the method of Haarmann et al. (2003), is illustrated in Table 1. Because the cue's color usually matched the color of the memoranda, we expected that participants often would unintentionally use the color of the cue as redundant information (cf. Kane & Engle, 2003). If so, the occasional color mismatch should be detrimental. We present results that can be explained on the premise that attention stores and retrieves information, supplementing passive, attention-free storage.

Table 1 An example of trial types in Experiment 1

Trial type	Event number	Word	Printed color
Any	1	Pelvis	Red
Any	2	Chest	Red
Any	3	Lung	Red
Any	4	Shoulder	Red
Any	5	Skunk	Blue
Any	6	Monkey	Blue
Any	7	Pig	Blue
Any	8	Cat	Blue
Any	9	Chisel	Green
Any	10	Screw	Green
Any	11	Crowbar	Green
Any	12	Pliers	Green
Semantic/match	13	ANIMALS?	Blue
Semantic/mismatch	13	ANIMALS?	Red or green
Semantic/neutral	13	ANIMALS?	Black
Color-name/match	13	BLUE?	Blue

This example shows recall of animals in medial position in the list presented in blue, for all four trial types. The experiment included tests of items from various categories, list positions, and colors, but always with four words in a row from each of three categories, as in the example

Postle (2003, Experiment 4) carried out a related task and interpreted it differently, and it is important to consider that work in the context of our own. Postle used a running memory span task (with relatively slow rates of presentation), in which series of consonants were presented with an unpredictable end point, followed by a probe consonant that was to be judged as matching or not matching one of the most recent four consonants. The list and probe items occurred in different colors, though the instructions noted that colors were irrelevant to the task. When there was a match, color did not matter. However, when there was no match (in which case the probe did match a consonant presented earlier in the list, but not in the relevant items, the most recent four), the probe was correctly rejected more often when it occurred in a color different from the color in which the same letter was presented earlier (about a 5% effect). This was taken as evidence that the match or mismatch between the encoding and retrieval contexts made a difference in short-term recall.

It is quite plausible that the match between encoding and retrieval contexts makes a difference in working-memory tasks. However, it is possible to go beyond that factor by varying the task demands, in order to observe effects of processing difficulty. In our first experiment, a match between the color of the words in the relevant category and the category cue occurred 75% of the time, which should make it difficult to keep in mind the task goal of attending to the word but not the color. In Experiment 2, however, a match between the color of the words in the relevant category and the category cue occurred only 25% of the time. In such a situation, it should be much easier to keep in mind the task goal. Therefore, it is predicted across studies that the effects of a color mismatch on conceptual span will be significant in Experiment 1, but not in Experiment 2.

Experiment 1

Method

Participants

Twenty-four undergraduate students (18 women, 6 men) who reported having English as a first language, normal or corrected-to-normal vision, and normal use of their dominant writing hand volunteered for course credit in an introductory psychology course.

Design and stimuli

The stimuli for the conceptual span task consisted of 72 concrete nouns in six semantic categories (12 nouns per category). In each of 48 trials, 12 items were presented sequentially at the rate of one word every 1,500 ms. The items were clustered in semantic categories. The first-four, middle-four, and final-four items each belonged to a different semantic category (e.g., body parts, animals, and tools) and were shown in different colors (red, blue, or green). Participants were cued to recall words belonging to a semantic category or a color group.

Cues were also shown in color. These included color names shown in the same color to create a predominance of match trials. The semantic cues were shown in:

1. The same color as the relevant list items (matching), or
2. The color of a different set of list items (mismatching), or
3. A neutral color not used for any list items (black)

This arrangement is shown in Table 1.

The number of matching, mismatching, and neutral semantically-cued trials was 12, 6, and 6 respectively, whereas all 24 color-name-cued trials were matches. Across semantic and color-name cues together, the cue color therefore matched the color of the cued list items in 36 out of 48 trials (75%). The semantic categories and words within categories were randomly assigned in each trial. Each category and color name was cued equally often. The beginning, middle, and final clusters of words were cued equally often in color-name and semantic name trials.

Procedure

Participants were seated at a computer and tested individually in a session lasting 30–40 min. The experimenter read the instructions and led the participants through an example. Participants read aloud the complete list of items and semantic categories before beginning four practice trials with two semantic and two color-name cues.

A ready screen appeared at the beginning of each practice and test trial, and participants pressed the "spacebar" to initiate trials. The list items were horizontally and vertically centered onscreen and presented in lower-case letters. The order of the colors of the three sets of four consecutive words (from three different semantic categories) was random in each trial. The cue was horizontally centered at the top of the screen, presented in uppercase letters, and followed by "?." Four lines numbered 1–4 appeared beneath the cue. Participants typed their responses there, using the "enter" key to advance to the next line or to leave an item(s) blank. The cue remained onscreen for the duration of the recall response.

Scoring

Separate scores were calculated for each experimental condition. Dividing the number of words recalled in each trial by four, the possible number of words that could be recalled, yielded the proportion correct in each trial.

Results and discussion

Participants typed in any order the words they remembered to be associated with each cue. Omissions and false recollections were counted as errors. Misspellings were not counted as errors when the word was decipherable. The dependent variable was the participants' conceptual span scores, measured as the mean proportion correct in each trial. Semantically-cued trials were at first analyzed without color-name-cued trials because this was not a completely crossed design. Means and standard deviations are shown in Table 2. (The results are shown separately for the first and second halves of the experiment so that the first half of the experiment can be compared with the same number of trials carried out in Experiment 2.)

In the analysis of semantically-cued trials, there was a significant effect of cue color type (matching, mismatching, and neutral) when submitted to a repeated-measures ANOVA, $F(2, 46) = 8.21$, MSE = .01, $p < .001$. Based on Keppel's (1991) formula for repeated measures, the effect size (omega squared) was 18. By pairwise comparisons, the proportion correct in mismatch trials ($M = .54$) was significantly lower than in match ($M = .62$) or neutral ($M = .63$) trials, which did not differ. This is critical evidence in support of the primary hypothesis. We believe that temporary attention to the prepotent response to color displaced the task goal, and consequently the relevant memoranda, from the focus of attention. Interference from the prepotent response to color hurt memory performance relative to the match and neutral conditions. The neutral condition served as a baseline measure of performance, and the fact that performance was equivalent in the match and neutral conditions suggests that the mismatch effect was indeed attributable to interference.

Participants never actually reported items corresponding to the color of the mismatched cue. That is not surprising given that the semantic cue remained on the screen during the response.

There was an additional effect of cue word type. Performance was worse in color-name-cued trials than in semantically-cued trials. Overall, mean performance in semantically-cued trials ($M = .59$, $SD = .11$) was better than performance in color-name-cued trials, $t(\text{df} = 23) = 7.03$, $p < .001$.

The results of Experiment 1 support the hypothesis that momentary distraction interferes with temporary memory. A passive storage-only model might anticipate our findings if the cue in the mismatch condition delayed recall for longer than in the other conditions, allowing more decay of the buffer contents. However, the mean response time on correct items did not differ as a function of matching (3,935 ms), mismatching (4,109 ms), or neutral (4,148 ms) semantic trials in a repeated-measures ANOVA, $F(2, 46) < 1.0$, MSE = .514317, n.s. Decay cannot account for the effect of mismatch on accuracy.

Additional analyses were conducted to determine if the effect sizes changed across the session. Separate analyses of the first half of the trials of each type and of the second half of the trials of each type were carried out. In the first half, a repeated-measures ANOVA of semantic-cue trials revealed a significant effect, $F(2, 46) = 6.43$, MSE = .025, $p < .01$. Pairwise comparisons revealed that performance in mismatch trials ($M = .52$) was significantly poorer than in matching trials ($M = 0.65$) or neutral trials ($M = .67$), which did not differ from one another. Another analysis showed that performance in semantically-cued trials ($M = .61$, $SD = .13$) was better than performance on color-name-cued trials ($M = .47$, SD = .16), $t(23) = 4.51$, $p < .001$. An analysis of the semantically-cued trials in the second half of the experiment showed no statistical differences among the mismatch ($M = .55$), match ($M = .59$), and neutral ($M = .60$) conditions, $F(2, 46) < 1.0$, MSE = .021, $p > .5$, though it was still the case that semantically-cued trials ($M = .58$, SD = .11) yielded better performance than color-name-cued trials ($M = .46$, $SD = .15$), $t(23) = 4.27$, $p < .001$. The non-significance of the effect of the type of semantic-cue trial in the second half of the experiment suggests that participants may have been able to learn to ignore the color of the probe to some extent. They could not have learned to ignore the colors of the memoranda because those were needed for the response 50% of the time.

The fact that there was a decrease in performance in the match and neutral trial types in the second half of the experiment compared with the first half suggests that there also may have been fatigue or proactive interference affecting performance as the experiment continued.

Lastly, let us clarify how we believe that the results are related to a limited-capacity mechanism. Assume for the sake of argument that all 12 words in a list were encoded into an activated, temporary but capacity-unlimited form of memory. Requesting recall of items from a category of four items resulted in 63% correct recall in the neutral condition, or 2.5 words. We think that this is the number of words recalled from activated memory into the focus of attention and awareness. It is slightly smaller than the estimate based on Cowan (2001), but that may be because, in fact, not all 12 words remain in an activated form long enough to be available when the time comes to retrieve words into the focus of attention.

Experiment 2

The purpose of Experiment 2 was to test the hypothesis that the presence of the mismatch effect depends on the task context and the relevance of color to the goal at hand. As described above, the task in Experiment 1 contained a majority of match trials, thereby creating a prepotent response to color. Research on working memory capacity and the Stroop effect (Kane & Engle, 2003; Long & Prat, 2002) shows this to be a critical factor. For example, Kane and Engle (2003) found a negative relationship between individual differences in working memory capacity and the Stroop effect, but only when the Stroop task contained a majority of congruent trials (e.g., the word ‘‘red’’ shown in the color red). When the task was so biased, those with less working memory capacity were more likely to lose track of the task goal (i.e., naming the color shown) and rely on the prepotent response of reading the word shown. When the Stroop task contained few or no congruent trials, however, span was unrelated to the Stroop effect. In our second experiment, trials were congruent between the relevant category and the recall cue only 25% of the time, reducing the likelihood that participants would slip into a response mode in which the sometimes-misleading color information is used to respond to category cues.

Method

Participants

Twenty-four new undergraduate students (15 women, 9 men) who did not participate in Experiment 1 were selected from the same pool of participants as in that experiment.

Apparatus, stimuli, and procedure

These were identical to Experiment 1 except for a modification in the trial types, as shown in Table 2. The distribution of matching, mismatching, and neutral trials for color cues was changed to be the same as the distribution for semantic cues: three matching, six mismatching, and three neutral trials. Also, the number of total trials was reduced from 48 to 24, inasmuch as the significant effect in Experiment 1 was localized in the first half of the experiment.

Results and discussion

In a 2×3 repeated-measures ANOVA, there was a significant interaction between cue word type (semantic or color-name) and cue color type (match, mismatch, neutral), $F(2, 46) = 3.22$, MSE = .02, $p < .05$. The means and standard deviations are shown in Table 2. The difference among cue color types was tested at each level of cue word type (semantic and color-name). For semantic category cues, there was no difference among cue color matches ($M = .55$, $SD = .13$), mismatches ($M = .56$, $SD = .12$), and neutral trials ($M = .56$, $SD = .16$), $F(2, 46) < 1.0$, MSE = .01, n.s. This absence of an effect shows that the mismatch between cue color and noun color only affected performance when the cue color was usually relevant (in Experiment 1, but not here in Experiment 2). The absence of an effect in Experiment 2 is unlikely to be due to low power. Given a correlation between the mismatch and neutral conditions of $r = .474$, and given the standard deviations

Table 2 Means (and SD) of the proportion of words recalled for semantic category and color-name cues in Experiments 1 and 2, and percent of trials of each type presented

Data	Number of trials	Semantic-category cues			Color-name cues		
		Match	Mismatch	Neutral	Match	Mismatch	Neutral
Experiment 1							
Mean recall (SD)							
First half of trials	24	.65 (.14)	.52 (.20)	.67 (.19)	.47 (.16)	–	–
Second half of trials	24	.59 (.14)	.55 (.20)	.60 (.15)	.46 (.15)	–	–
All trials	48	.62 (.11)	.54 (.13)	.63 (.14)	.47 (.13)	–	–
Distribution of trial types (percentages)		25	12.5	12.5	50	0	0
Experiment 2							
Mean recall (SD)	24	.55 (.13)	.56 (.12)	.56 (.16)	.53 (.21)	.41 (.14)	.45 (.18)
Distribution of trial types (percentages)		12.5	25	12.5	12.5	25	12.5

shown in Table 2, a power analysis indicated that the power to detect an effect between these conditions of the same magnitude as the effect obtained in Experiment 1 was .82 by a *t* test.

Cue color type affected performance in trials with color-name cues, as a repeated-measures ANOVA indicated, $F(2, 46) = 4.77$, MSE $= .02$, $p < .05$. Pairwise comparisons were conducted, and performance was significantly better in color match trials ($M = .53$, $SD = .21$) than either mismatch ($M = .41$, $SD = .14$) or neutral trials ($M = .45$, $SD = .45$), which did not differ. This Stroop-like effect indicated that the mismatch between cue color name and cue color affected performance even when cue color was not an often-relevant cue, and it shows that cue color was, in fact, processed even though it did not influence semantic cue judgments.

General discussion

Experiment 1 demonstrated that color cue signaling a prepotent response impaired working memory when the prepotent response did not match the task goal. Two experiments together showed that the effect of a mismatching cue color depends on making color frequently relevant, which was not the case following the reduction of color-relevant trials from 75% of the trials in Experiment 1 to 25% of the trials in Experiment 2. The mismatch effect suggests that items can be stored and retrieved in working memory only with the help of attention, and that overcoming a goal conflict uses the same resource.

It still might be possible to hold on to the view that the color manipulation was effective in Experiment 1 primarily because it affected the similarity between the encoding and retrieval contexts. To hold this view, however, it would have to be assumed that individuals in Experiment 2 quickly learned not to encode the color of the probe in a way that could adversely affect performance. (As indicated above, they could not ignore the colors of the memoranda because those were needed for the response.) Arguing against this hypothesis, however, the color of the probe assisted color-name-cued performance when it matched the cued color. Therefore, the hypothesis may have to be refined to state that participants learned to ignore the color of the probe only in the context of semantic cues.

A remaining question is exactly what difference between Experiments 1 and 2 accounted for the difference in results (i.e., a mismatch effect in semantic-cue trials of Experiment 1 only). The most salient difference in procedure was that the color of the cue was a correct indication of the color of the relevant items in 75% of the trials in Experiment 1, but only 25% of the trials in Experiment 2. However, there also was a difference in the proportions of match, neutral, and mismatch trials in the two experiments, and it remains to be seen whether that plays a role. Another, related question is why performance levels in the match and neutral semantic-cue trials were higher in Experiment 1 than in Experiment 2. It may be that the usual absence of color interference was helpful for match and neutral trials in Experiment 1 because it allowed fuller concentration on the semantic cues.

Other, unpublished results that we recently have obtained further argue against that hypothesis, and in favor of the hypothesis that the color mismatch could function as an attentional distraction. We used a running memory span task with spoken digit stimuli, presented at the rapid rate of four items per second, and we inserted a distracting task between the digit-presentation and digit-recall phases of that memory task. In the easy version of the distracting task, participants were to click on a box that appeared; in the difficult version, participants were to click on the side of the screen opposite the box. This is a manual-response analogue of the prosaccade (easy) and antisaccade (difficult) tasks of Kane et al. (2001). When the box task could be performed in a leisurely manner there was no effect on running memory span, but, when the box task had to be performed quickly, the difficult version of the box task reduced performance relative to the easy version (and running span was lower overall). The detrimental effect of the difficult processing task on span occurred even among trials with correct box responses matched for response times across the easy and difficult versions. These results are not readily interpreted by the hypothesis that the difficult task allowed more decay of memory, but can be interpreted with the hypothesis that the difficult task was more effective in shifting the focus of attention so that it could not be used as much for storage of running span task stimuli. Presumably, only digits that are transferred from an activated form to the focus of attention can be recalled, and a diversion of attention by the antisaccade analogue interferes with that process.

The present results contrast with long-term memory research in a potentially important way. Craik and colleagues (e.g., Craik, Naveh-Benjamin, Ishaik, & Anderson, 2000) have found that long-term recall is not sensitive to divided attention at the time of retrieval. The present finding that a processing mismatch at the time of retrieval was effective (Experiment 1) may have occurred because it involved recall from the focus of attention rather than from long-term memory.

In sum, we have presented two studies that, taken together and interpreted in the light of other recent results in our laboratory, suggest that attention serves as a form of memory storage. That form of storage cannot be simultaneously zoomed in to achieve maximal control in a goal-conflict situation (e.g., Conway et al., 2001; Kane & Engle, 2003) and zoomed out to achieve apprehension of a maximal number of items from sensory memory (Cowan, 2001). As suggested by Cowan (2005), there sometimes may have to be a compromise between these extreme states of attention and awareness.

In additional support of this suggestion of an adjustable scope of attention, it recently has been observed that, although individuals can recognize the most recent item in a presented list more quickly than prior items (McElree, 2001), with practice the advantage expands to the most recent four or so items (Verhaeghen, Cerella, & Basak, 2005). The latter result suggests that attention at first must be strongly focused on each item as it is presented, but that, with sufficient task familiarity, attention can be focused on the last several items at once.

In addition to the practical implications of this work, such as leading to extensions that may improve our understanding of individual differences in attention and working memory, theoretical implications have been noted. This sort of research may even lend empirical credence to subjective impressions of human states of awareness, which can range from intense and narrowly focused to more extensive and widely focused.

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