VISUAL COGNITION, 2006, 14 (1), 37–54

Psychology Press
Taylor & Francis Group

Visual working memory for trained and novel polygons

Diyu Chen, Hing Yee Eng, and Yuhong Jiang
Harvard University, Cambridge, MA, USA

This study investigates whether training changes the capacity of visual working memory (VWM). We compared change detection performance for novel and trained polygons. During training, subjects developed familiarity with 8 random polygons. Specifically, 4 polygons from a set of 8 were presented on each trial. After a brief retention interval, one of the polygons changed and subjects judged which one had changed (Exps. 1–2) or whether there was a change (Exp. 3). After 320 training trials, subjects could recognize the trained polygons with high accuracy. In the testing phase, subjects carried out the same task again, only this time each trial might contain all familiar polygons, all novel polygons, or a mixture of familiar and novel polygons. We found that change detection performance improved during training, but the improvement was not limited to trained polygons. We suggest that familiarity of non-nameable shapes plays a limited role in modulating the capacity of VWM.

Visual working memory (VWM) allows visual information to be retained momentarily after the stimuli's disappearance (Logie, 1995). It maintains a sense of temporal continuity in a constantly changing environment, yet it is severely limited in capacity. Only a few visual objects can be held in VWM simultaneously (Alvarez & Cavanagh, 2004; Luck & Vogel, 1997; Raffone & Wolters, 2001). This severe capacity limitation places significant demands on the visual system to retain only the most important information in VWM. Surprisingly, while many studies have focused on demonstrating the capacity limitation of VWM, few have investigated how this limitation is affected by practice and learning. How does practice in a VWM task affect one's capacity limitation? Can we hold more familiar objects than unfamiliar ones

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Please address all correspondence to: Yuhong Jiang, Department of Psychology, Harvard University, 33 Kirkland Street, WJH 820, Cambridge, MA 02138, USA. Email: yuhong@wjh.harvard.edu

This study is supported by NSF 0345525. We thank Steve Luck and an anonymous reviewer for comments, and Livia King for data collection.

http://www.psypress.com/viscog DOI: 10.1080/13506280544000282

in VWM? In this study we wish to address these questions with respect to VWM for non-nameable, random shapes.

More broadly, experience and learning are prominent candidate mechanisms that affect visual processing. Many aspects of visual cognition are sensitive to learning (Green & Bavelier, 2003). For example, the speed of visual search is improved by practising the same search task for several sessions (Logan, 1988; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977), dual-task interference is significantly reduced after thousands of trials of practice (Schumacher, Sey mour, Glass, Kieras, & Meyer, 2001; van Selst, Ruthruff, & Johnston, 1999), and visual search is more efficient for familiar (e.g., "2"s and "5" s) than for unfamiliar items (e.g., rotated "2"s and "5"s; Wang, Cavanagh, & Green, 1994). In addition to general procedural learning, specific information about visual targets can be acquired, often in an implicit manner. The visual system is highly sensitive to repeated target locations (Maljkovic & Nakayama, 1996), incidental features such as the target's colour (Maljkovic & Nakayama, 1994), sequences of target locations and motor responses (Nissen & Bullemer, 1987; Seger, 1994), and associations between targets and distractors (Chun & Jiang, 1998, 1999).

Learning not only facilitates perception but also enhances memory. Using lists of digits, Hebb (1961) observed that repeating the same list every third trial enhanced subjects' digit spans. The same effect is seen in a visual analogue of the digit span task—the Corsi Block task, in which a sequence of locations is pointed out by an experimenter for subjects to repeat (Corsi, 1972; Kemps, 2001). Visual working memory for simultaneously presented items, however, fails to show unambiguous improvement (Olson & Jiang, 2004; Olson, Jiang, & Sledge, in press). In a heroic study, Olesen, Westerberg, and Klingberg (2004) gave subjects extensive training over a 5-week period on VWM of spatial locations. Though there is increased activation in the prefrontal and parietal cortex after training, memory accuracy is not significantly affected or only moderately improved.

Finally, expertise in certain domains can enhance one's visual memory for those domains. For example, after examining a chessboard briefly, chess experts can recreate the pieces from memory better than novices can (Chi, Glaser, & Farr, 1988), but such improvement is seen only for a board that presents a plausible midgame arrangement. The complexity of chess, however, has made it difficult to isolate how visual working memory *per se* is affected by experience.

FAMILIARITY AND CHANGE DETECTION

Recent studies using the change detection paradigm (Rensink, 2002) have produced mixed results regarding the role of familiarity in this task. Pashler (1988) presented subjects with an array of upright or inverted letters. After a retention interval of 67 ms to 217 ms, the probe array was presented for subjects to detect a change. Pashler found that change detection of letters was not better than that of inverted letters, suggesting that familiarity with letters was not beneficial. In contrast, Alvarez and Cavanagh (2004) tested change detection of upright digits,  and , or 90° rotated digits,  and . They found that performance was better with upright digits than with rotated digits, suggesting that familiarity could help visual change detection. It is unclear what factors contributed to the inconsistency observed in these results. One possibility is that inverted letters allow quick recognition (Corballis, Zbrodoff, Shetzer, & Butler, 1978), reducing the difference between inverted and upright letters. In contrast, rotated "2"s and "5"s do not allow rapid discrimination, as shown in Wang et al.'s (1994) study. Alternatively, perhaps Pashler's procedure, in which a very short delay interval was used, discouraged subjects from verbally naming the letters, while subjects in Alvarez and Cavanagh's study might have relied on verbal coding for the familiar digits (but not for rotated digits). Thus, it is unclear how familiarity with alphanumerical characters affect change detection performance.

In this study, we investigated VWM for random polygons using a change detection task. Random polygons were preferred over alphanumerical characters because they were visually complex but non-nameable. To prevent subjects from developing idiosyncratic verbal labels for trained random polygons, an articulatory suppression task (Baddeley, 1986), in which subjects constantly said "teddy bear", was used throughout the experiments. This manipulation ensured that effects of familiarity were not due to the presence of verbal labels for familiar objects. In addition, because subjects were initially unfamiliar with all polygons, we were able to examine the gradual change of performance with training.

We report three experiments that differed in the duration in which subjects were allowed to encode the random shapes into their VWM. In all experiments, we first trained subjects on a set of eight random polygons until they were able to recognize these shapes with high accuracy. We then compared VWM for trained shapes with that for novel shapes.

Training can enhance change detection of familiar shapes due to several reasons. First, with increased familiarity, a random polygon can be encoded with increased fidelity, facilitating later change comparison. Second, familiar shapes have access to long-term memory, so they can be quickly recognized. Familiar shapes can thus be retained as both a visual shape in VWM and an activated node in visual long-term memory. Such dual coding can be more advantageous than single coding in VWM. Finally, visual distinctiveness between one shape and another may increase as a function of familiarity: Familiar shapes may be subjectively more distinctive from one another than unfamiliar shapes are (Goldstone, 1998). The increased distinctiveness can make it easier to detect the change of one familiar shape to another than from one novel shape to another. All these factors may result in an enhancement in change detection performance.

Alternatively, training may fail to enhance VWM for trained shapes. This is because even though training can result in dual coding of a shape in short-term and long-term visual memory, the fidelity of visual information held in long-term memory may be substantially worse than that held in short-term memory. That is, the long-term coding for trained shapes is redundant to their short-term coding, so no advantage should be observed. The following experiments were designed to examine the role of training and familiarity in visual working memory.

EXPERIMENT 1: LIMITED ENCODING DURATION

The experiment was divided into four phases: Training, recognition-1, testing, and recognition-2. In the training phase, subjects performed a change detection task on a set of eight random shapes for 320 trials. On each trial, four shapes were presented for 400 ms. After a delay interval of 1000 ms, a probe display containing two shapes was presented. One probe shape matched one of the sample shapes while the other was drawn from one of the four shapes not presented on that trial. Subjects were told to identify which shape was new. To ensure that training was adequate, recognition-1 followed immediately after training. In this phase, two shapes, one trained and the other random, were presented side by side for subjects to pick out the previously trained shape. Our subjects were able to achieve high accuracy in recognition. This set up the stage for testing. During testing, subjects were presented with the same change detection task as used in the training phase, except that three types of trials were included. In the all-familiar condition, all four shapes presented in the sample display were among the trained shapes and when a shape changed, it changed to one of the trained shapes not shown on that trial. In the all-unfamiliar condition, all four shapes in the sample display were newly generated random polygons. When a shape changed, it changed to another novel shape. Finally, in the mixed condition, two novel and two trained shapes were presented in the sample display. When one of the shapes changed, a novel shape always changed into another novel shape while a trained shape always changed to another trained shape not presented on that trial. Finally, to ensure that subjects continued to have persistent memory for the trained shapes, recognition-2 was carried out after the testing phase.

If visual working memory is modifiable by training, then change detection performance for all-familiar displays should be better than that for all-unfamiliar displays, and familiar polygons should have a competitive advantage over novel polygons in the mixed condition. In contrast, if visual working memory is relatively insensitive to training, then performance should not be affected by familiarity.

Method

Participants

Twelve students from Harvard University participated in this study for payment. They were 19–29 years' old; all had normal or corrected-to-normal visual acuity.

Materials and stimuli

Random polygons were generated by a computer program that could produce many (on the order of 10^5) novel shapes (Chun & Jiang, 1999). The shapes were visually distinctive, but no simple features could uniquely describe each one. Each shape subtended $2.5^\circ \times 2.5^\circ$ and was outlined in black against a uniform grey background. A set of eight polygons was randomly generated to comprise the trained set. These shapes varied for different subjects. Novel shapes were generated on a trial-by-trial basis and were also disparate for different subjects.

Procedure

Each subject was tested in four phases in the following order: Training, recognition-1, testing, andrecognition-2. Subjects were told to say "teddy bear" out loud throughout the experiment.

Training. On each trial, four shapes were selected from the set of eight shapes (Figure 1A). They were presented on a 2×2 grid, with the centre of each shape located 4° away from the fixation. A sample display of these four shapes was presented for 400 ms. After a blank retention interval of 1000 ms, a probe display containing two shapes was presented until subjects made a response. The probe shapes were presented randomly at two of the four locations previously occupied. One probe shape matched the sample shape previously at that location, while the other probe shape was selected from the remaining four shapes not presented in the sample display. Two small white digits, "1" or "2", were presented on the probe shapes. Subjects were told to press the corresponding digit at the position of the new shape. Accuracy feedback was provided after each trial. Figure IB shows a sample trial. Subjects received 12 practice trials and 320 training trials such that each of the eight random polygons was seen 160 times on the sample display.

Recognition-1. To verify the effectiveness of the training procedure, subjects were presented with eight recognition trials immediately after the training phase. On each trial, a trained shape and a novel shape were presented side by side (4° away from fixation). The trained shape was on the left side of the display in half of the trials and on the right side of the display

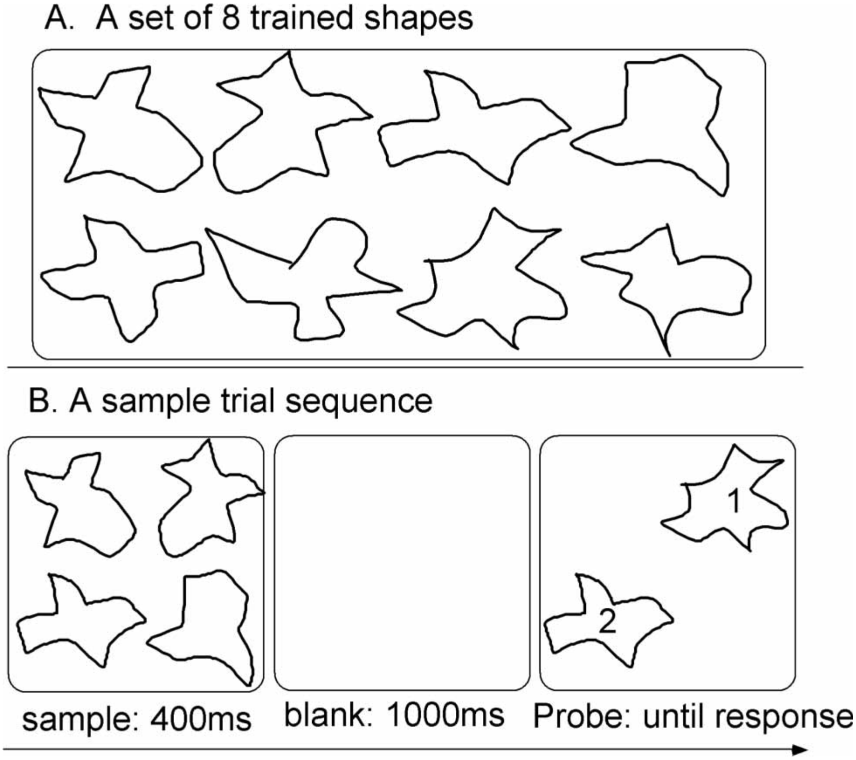

Figure 1. Stimuli used in this study. A: Sample of 8 trained shapes. B: Trial sequence.

in the remaining trials. The two shapes were presented until subjects made a response. Subjects pressed the left or the right arrow to report the position of the trained shape.

Testing. The testing phase contained three types of trials. On the sample memory display, the four shapes were all-familiar (25% of trials), all-unfamiliar (25% of trials), or mixed (50% of trials; with two familiar and two novel shapes). The category of the probe shapes (familiar or unfamiliar) matched the category of the sample shapes. On all-familiar trials, the probe display contained one familiar shape that matched the sample shape at its position and one familiar shape not shown on the sample display. On all-unfamiliar trials, the probe display contained one novel shape that matched the sample shape at that position and one novel shape not previously shown. On the mixed trials, the probe display always contained two shapes of the same category (i.e., two familiar shapes or two unfamiliar shapes, equally likely); one matched the shape at its position and the other was a nonmatch.

In other words, the trials were designed such that familiar shapes would not change into unfamiliar shapes and vice versa. This design was necessary because our pilot study showed that a change in category was easy to detect as subjects could quickly categorize a shape as familiar or unfamiliar without remembering its exact shape. Because we were interested in VWM for the exact shape rather than for category membership, we deemed it necessary to change shapes only within the same category.

Just like the training phase, each sample display of four shapes was presented for 400 ms followed by a 1000 ms interval. The probe display of two shapes was then presented until subjects made a response. There was a total of 96 testing trials, with different conditions randomly intermixed in the presentation.

Recognition-2. To ensure that subjects did not forget the trained shapes during testing, we tested subjects' recognition performance again after the testing phase. The recognition procedure was identical to recognition-1, although the trial order was randomized.

Equipment

Subjects were tested individually in a room with normal interior lighting. They viewed a computer screen from an unrestrained distance of about 57 cm, at which distance 1 cm corresponded to 1° visual angle.

Results

Training. We binned 80 training trials into a single epoch. Figure 2 (left) shows mean accuracy in the training phase. A repeated-measures ANOVA shows a significant main effect of epoch, $F(3, 33) = 3.61, p < .023$, suggesting that the overall accuracy improved significantly during training.

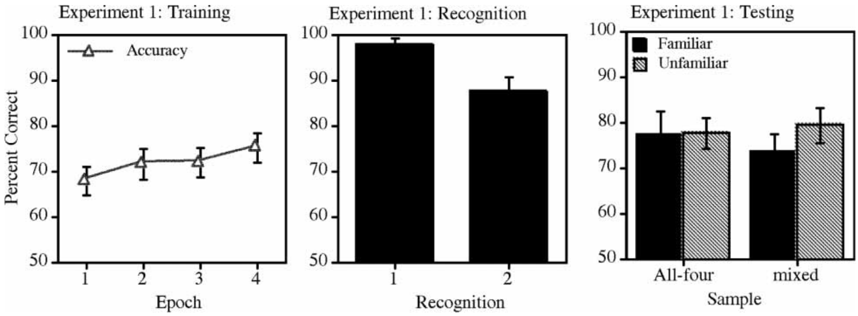

Figure 2. Results from Experiment 1. The error bars show between-subject standard error of the mean.

Recognition-1 and recognition-2. Figure 2 (middle panel) shows mean recognition accuracy. Immediately after training, subjects recognized the trained shapes with 98% accuracy, which was significantly above chance (50%), $t(11) = 34.12$, $p < .001$, and not significantly different from perfect (100%), $t(9) = -1.48$, $P > .15$.

Recognition accuracy dropped to 88% after the testing phase, which was still significantly above chance, $t(11) - 10.90, p < .001$, but significantly lower than that of recognition-1, $t(11) - 2.42, p < .034$. The reduction in accuracy suggests that the new shapes seen during the testing phase interfered with memory for the trained shapes, showing retroactive interference in memory (Crowder, 1976).

Testing. Figure 2 (right) shows testing accuracy separately for familiar and unfamiliar shapes and for displays containing four shapes of the same category or a mixture of familiar and unfamiliar shapes. Accuracy in the all-familiar condition was not statistically different from that in the all-unfamiliar condition, $t(11) = 0.10, p > .50$. Surprisingly, accuracy in the mixed condition was affected by familiarity: Performance was higher when the novel shapes were probed than when the familiar shapes were probed, $t(11) - 3.40, p < .006$.

An ANOVA on familiarity (familiar vs. unfamiliar) and sample category (single category vs. mixed categories) revealed a marginally significant main effect of familiarity, $F(\mathrm{l}, 11) - 3.66$, $p < .09$, driven primarily by higher accuracy with novel shapes in the mixed condition. The main effect of sample category (all vs. mixed) was not significant, $F < 1$, n.s. While performance on single-category trials was unaffected by the familiarity of the shapes, that on mixed-category trials was sensitive to familiarity. In the latter, familiarity was detrimental to performance. The interaction between familiarity and sample category, however, failed to reach significance, $F(1, 11) = 1.60, p > .20$.

Discussion

Is the capacity of visual working memory sensitive to practice? Can we remember more familiar objects in VWM than unfamiliar objects? Results from Experiment 1 address these issues in two ways. First, performance in a change detection task improved significantly as a function of training. Specifically, in the training phase, subjects detected a shape change with higher accuracy in later training epochs than in earlier ones, suggesting that procedural learning was observed in this task. Second, the improvement seen during the training session was not restricted to the trained shapes. In the testing phase, accuracy in detecting a shape change among trained shapes was not higher than that among novel shapes. This suggests that any improvement we observed in the training session was general procedural learning. In fact, when a sample display contained both familiar and unfamiliar shapes, accuracy was higher when the unfamiliar shapes changed. This result ran counter to a "familiarity makes better" effect. It probably resulted from greater effort used to encode the novel shapes than the trained shapes on mixed trials. Thus, while we have evidence that a moderate amount of training enhances performance in a change detection task, this improvement is not specific to the trained shapes. Familiarity with object shapes is insufficient to increase the capacity of VWM specific to these shapes.

EXPERIMENT 2 UNLIMITED ENCODING DURATION

Experiment 1 shows that training with a set of objects in a change detection task improves performance, but the improvement is not specific to the trained objects. This suggests that familiarity with the memory materials has a limited role in affecting the capacity of visual working memory. However, one criticism of Experiment 1 is that the training procedure may not have been optimal for establishing a solid long-term memory for the trained shapes. In particular, because the sample display was presented for only 400 ms during training, subjects might not have had a sufficient amount of time to encode the shapes effectively. In fact, recognition of the trained shapes declined after testing, suggesting that the memory trace for these shapes was not strong enough to resist retroactive interference. In Experiment 2, we used a training procedure that increased the strength of the resulting memory. Specifically, in the training phase we allowed subjects to view a given sample display for as long as they wished. Once they have encoded the shapes into their memory, subjects pressed the spacebar to clear the sample display. After a retention interval of 1000 ms, a probe display containing two items was presented until a response was made. Subjects picked out the shape that did not match the sample shapes.

After the training phase, subjects were tested for their recognition memory of the trained shapes. They then participated in the testing phase that included sample displays with all familiar, all unfamiliar, and mixed shapes. In the testing phase, we presented the sample memory display for either a limited amount of time (400 ms, just like in Experiment 1) or for as long as subjects wished. We were interested in whether subjects could now remember the familiar shapes better than the unfamiliar ones, and whether this effect was affected by the duration of the sample memory display. A second recognition memory test followed the testing phase.

Method

Participants

Twelve new subjects participated in this experiment for payment.

Procedure

The procedure was similar to that of Experiment 1. Each subject completed four phases: training, recognition-1, testing, and recognition-2. The main difference between the two experiments was the duration of the sample memory display.

In the training phase of Experiment 2, each sample display was presented for an unlimited amount of time until the subjects pressed the spacebar. The retention interval between the offset of the sample memory display and the onset of the probe display was 1000 ms. There were 320 training trials, just like in Experiment 1.

In the testing phase, two durations were employed for the sample memory displays: Fixed (400 ms) or self-paced (until subjects' key press). These two types of trials were randomly intermixed in presentation. There were 192 total testing trials.

The recognition phases were the same as in Experiment 1.

Results and discussion

Training. We calculated the accuracy of change detection and the amount of time that subjects viewed the sample display. Figure 3 (left) shows the training results. Accuracy improved significantly during training, with a significant main effect of epoch, $F(3,\ 33) = 4.54, p < .009$. The improvement in accuracy was accompanied by a reduction in the amount of time that subjects viewed a sample display, $F(3,\ 33) = 6.05, p < .002$.

A direct comparison between Experiments 1 and 2 revealed a significant main effect of training epoch in accuracy, $F(3,\ 66) = 7.18, p < .001$, and a lack of interaction between experiment and epoch, $F < 1$. The main effect of

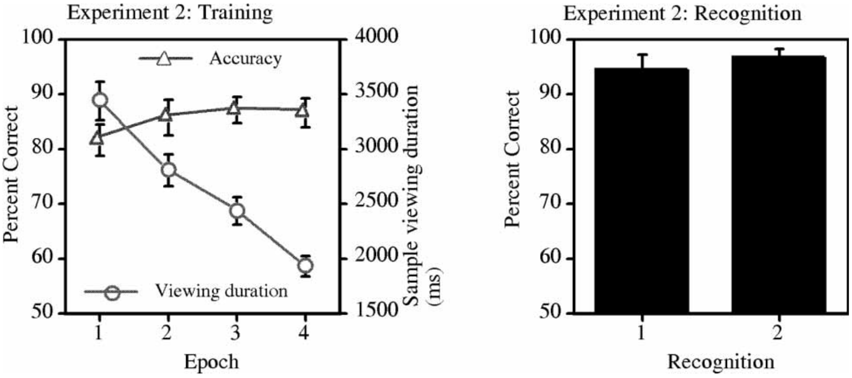

Figure 3. Training and recognition data from Experiment 2. The error bars show between-subject standard error of the mean.

experiment was significant, $F(1, 22) = 11.40$, $p < .003$, suggesting that extended viewing was beneficial to encoding of the novel shapes.

Recognition. Data from one subject's recognition performance were lost, so this analysis was based on the remaining 11 subjects' data. Recognition accuracy was significantly above chance in both recognition-1 and recognition-2 (Figure 3, right), p values $<.001$. There was no evidence that recognition memory decayed during testing, $t(10) = -0.80$, $p > .40$.

A direct comparison between Experiments 1 and 2 revealed no main effects of recognition session (recognition-1 vs. recognition-2), $F(1, 21) = 2.40$, $p > .13$, or experiment, $F(1, 21) = 1.17$, $p > .25$. However, the interaction was significant, $F(1, 21) = 5.83$, $p < .025$. The interaction was produced by a reduction in recognition after the testing phase in Experiment 1, but no reduction in Experiment 2. Thus, the training procedure used in Experiment 2 was successful at producing durable memory traces resistant to retroactive interference.

Testing. Figure 4 shows the performance in the testing phase, separately for trials with a limited sample duration (400 ms) and those with a self-paced duration.

Data from the limited-sample duration condition replicated those of Experiment 1. The main effects of category (mixed-category vs. pure category) was significant, $F(1, 11) = 8.47$, $p > .014$, with lower accuracy in the mixed-category condition, but the main effect of familiarity was not significant, $F(1, 11) = 2.53$, $p > .14$. There was a significant interaction effect, $F(1, 11) = 5.64$, $p < .037$. This interaction resulted because familiarity had a significant effect on mixed-category trials even though it had no effect on pure-category trials. On mixed trials, novel shapes were associated with better change detection performance than trained shapes, $t(11) -2.30$, $p < .042$, whereas this was not the case on pure-category trials, $t(11) - 0.42$, $p > .50$. The novelty

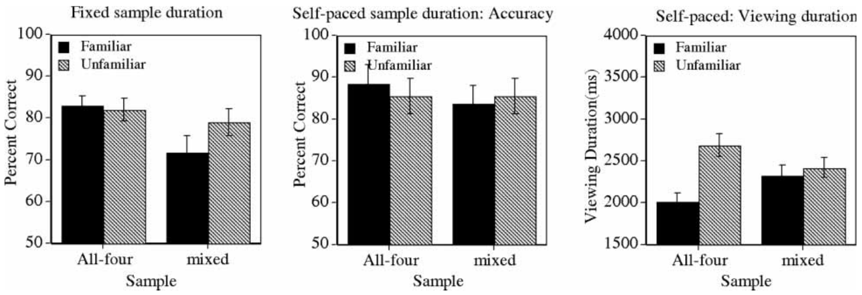

Figure 4. Results from the testing phase of Experiment 2. The error bars show between-subject standard error of the mean.

effect on the mixed trials was most likely a result of strategic shifts: When the encoding duration was limited, subjects paid more attention to the novel shapes at the cost of the trained shapes.

In the self-paced condition, the main effects of category ($F < 1$) and familiarity ($F < 1$) as well as their interaction, $F(1,\ 11) = 1.84, p > .20$, were all nonsignificant in accuracy. Thus, unlike the limited viewing duration condition, there was no need to bias attention towards the novel shapes when viewing duration was unlimited. On pure-category trials, subjects did spend a longer time viewing four novel shapes than four familiar shapes, $t(11) - 2.86$, $p < .015$. On mixed-category trials, viewing duration was comparable regardless of whether the familiar shapes or the novel shapes were later probed, $t(11) = -0.40, p > .50$.

Finally, an ANOVA on accuracy data using sample duration (limited vs. self-paced), category (mixed vs. pure), and familiarity (trained vs. novel) as factors revealed a significant main effect of sample duration, $F(1,\ 11) = 37.33$, $p < .00$, suggesting that a limited duration of 400 ms was not optimal for VWM encoding. The main effect of category was also significant, $F(1,\ 11) = 11.29$, $p < .006$, showing lower accuracy in the mixed displays. The main effect of familiarity was not significant, $F < 1$. However, the interaction between category and familiarity was significant, $F(1, 11) = 6.68$, $p < .025$, produced by the novelty effect in the mixed but not pure category conditions. The other interaction effects were not significant, all p values $> .20$.

EXPERIMENT 3: CHANGE DETECTION

In the first two experiments, our experimental design relied on a two-alternative-forced-choice (2AFC) procedure, in which one of two shapes on the test display changed and subjects discriminated between them. A correct response could be based on noting that one shape did not change, or that the other shape changed. Initially, this procedure was used to boost the overall level of accuracy, given that VWM for random polygons was notoriously poor (Alvarez & Cavanagh, 2004). However, because most VWM studies rely on the change detection paradigm, it is important that we demonstrate that our conclusions apply to the change detection task.[1] Testing additional subjects also increases our statistical power to detect small training effects.

Method

Participants

Twelve new subjects participated in this experiment.

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[1] We thank an anonymous reviewer for making this point.

Procedure

This experiment was similar to Experiment 1 in that subjects were tested in four consecutive phases: Training, recognition-1, testing, and recognition-2. However, the two experiments differed in the following ways.

First, during the training and testing phases, the task changed from a 2AFC task to a change detection task. In particular, on each trial four polygons were presented on the sample display for 400 ms. After a blank retention interval of 1000 ms, a test display containing four polygons was presented until subjects made a response. On half of the trials, the test display was identical to the memory display. On the remaining trials, one of the polygons changed its shape on the test display. Subjects pressed "same" or "different" to report whether they detected a change.

Second, to better counterbalance the trained and novel shapes across subjects, we created a total of 224 random polygons, 8 of which were randomly drawn to be the trained shapes while the others were assigned to be the novel shapes. The assignment was randomized across subjects, ensuring that the trained shapes for some subjects would be novel shapes for others and vice versa. This procedure minimized systematic differences between the trained and novel shapes.

Third, in the testing phase, only all-familiar or all-unfamiliar shapes were presented on the memory display in a trial. We no longer tested the mixed displays because strategic differences made the memories for familiar and novel shapes on those displays not directly comparable to each other (see Experiments 1 and 2). There were a total of 96 testing trials, randomly and evenly divided into all-familiar and all-unfamiliar trials. Within each type of trials, half of the trials contained a change while the other half contained no change. As in Experiment 1, when a familiar shape changed, it changed into another familiar shape not presented on that trial. When a novel shape changed, it changed into a new shape.

Results and discussion

We calculated accuracy, A′, as well as d′ and beta, for the training and testing phases. Results from the three measures (accuracy, A′, and d′) were qualitatively similar. Here we report accuracy and A′ (Donaldson, 1993). For both measures, .50 corresponds to chance performance while 1 corresponds to perfect performance. The Appendix shows hit and false alarm rates for each condition. Figure 5 shows the results.

Training. Subjects improved slightly across the four epochs of training, although this effect was not significant in either the accuracy, $F(3, 33) < 1$, or the A′ measure, $F(3, 33) < 1$. The change detection task appears to be less sensitive to procedural learning than the 2AFC task.

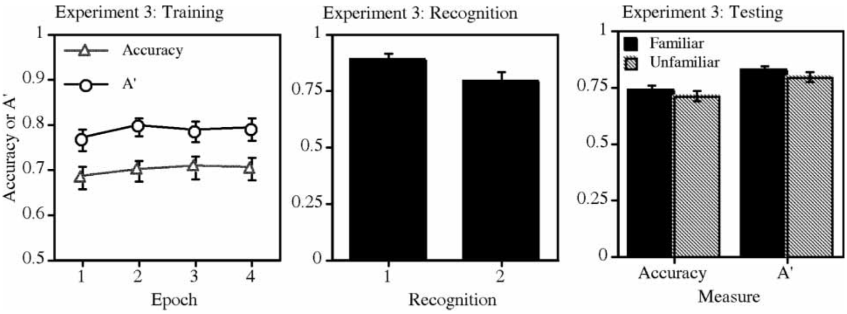

Figure 5. Results from Experiment 3. Accuracy and A′ were both plotted for training and testing. Error bars show standard error of the mean across subjects.

Recognition. Subjects were quite successful in recognizing the trained shapes both immediately after training and after testing. There was some memory decay: Recognition after testing was worse than that before testing, $t(11) = 2.69$, $p < .021$, although both values were significantly above chance (p values $< .001$).

Testing. Change detection performance was not affected by familiarity. There was no effect of familiarity on accuracy, $t(11) = 1.07$, $p > .30$, or on A′, $t(11) = 1.32$, $p > .21$. Thus, results from Experiments 1 and 2 generated to a change detection task.

Experiments 1–3. To increase statistical power for detecting a familiarity effect, we pooled data from all three experiments. These data were restricted to the testing phase when the sample display presentation was 400 ms. The overall accuracy for familiar polygons ($M = 0.78$) was not significantly different from that for novel polygons ($M = 0.77$), $t(35) = 0.69$, $p > .49$. Assuming a medium effect size, the power of this analysis was .68. As we will discuss below, this analysis still does not eliminate the possibility that extended practice could enhance the familiarity effect. What is clear, however, is that a moderate amount of training has a negligible effect on VWM for trained shapes.

GENERAL DISCUSSION

In this study, we showed that training in a change detection task led to general procedural learning (Experiments 1–2), but the learning was not specific to the trained shapes. Because the change detection task involves several processes, the procedural learning can result from many sources, such as increased efficiency at encoding or at making more accurate response decision. Procedural learning is sometimes but not always observed in visual working memory tasks. For example, it was not observed in Experiment 3. When it is observed, the magnitude of improvement has typically been small. For example, Olson and Jiang (2004) found no improvement in a change detection task of spatial locations over a 1 hour training session. Subjects in Olesen et al.'s (2004) study did improve after multiple sessions of training on a spatial VWM task, but the improvement was moderate. Whether procedural learning reflects a genuine increase in the capacity of VWM is debatable. As noted earlier, the multi-components of the change detection task has provided an opportunity for improvement in several aspects of the task, such as increased efficiency at encoding the stimuli or increased precision at making a response decision.

Because learning acquired during the training phase transferred completely to novel shapes, long-term familiarity with a set of random shapes had limited impact on VWM. This absence of a familiarity effect was observed even when subjects were able to recognize trained shapes at nearly 100% accuracy. The discrepancy between their recognition performance and change-detection performance is understandable given that a sense of familiarity is sufficient for classifying a shape as trained or novel, but additional knowledge about the exact shape is necessary for change detection.[2] Familiarity also affected subjects' encoding bias on displays containing a mixture of familiar and novel shapes. When such sample displays were presented briefly for 400 ms, subjects' attention was biased toward the novel shapes, resulting in better performance when the novel shapes, rather than the familiar shapes, changed. Even though subjects were sensitive to familiarity in recognition and in encoding bias, they were unable to retain the familiar shapes more effectively in VWM.

These results are consistent with Pashler's (1988) finding that familiarity with alphanumerical characters had no effect on visual change detection. In Pashler's study, change detection for upright letters was not better than that for inverted letters, even though it took subjects longer to recognize inverted letters. Our results are also consistent with Williams and Simons' (2000) study on change detection of fribble-like stimuli. Williams and Simons trained two groups of subjects to categorize novel objects, known as "fribbles". One group learned to categorize individual fribbles with specific verbal labels while the other learned to categorize fribbles into separate groups. Williams and Simons found that neither subject group was more accurate in detecting part changes in the fribbles compared with a third, untrained group. Training did influence response bias, however, in that it affected subjects' likelihood to report whether a change had occurred. Memory sensitivity, however, was not affected by categorization training. Together, these studies suggest that long-term coding

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[2] We thank Dr. Steven Luck for raising this point.

of a familiar object has limited impact on current, online processing of the objects. This conclusion is consistent with Wolfe and colleagues' findings in visual search. Repeatedly searching for different targets on the same search display led to no improvement in search slope (Oliva, Wolfe, & Arsenio, 2004; Wolfe, Klempen, & Dahlen, 2000).

While we think that familiarity generally does not enhance visual working memory, there are potential exceptions to this rule. In particular, we conjecture that an extremely high degree of familiarity, over days or years of training, with stimuli that are subtly different from one another, can enhance change detection of these stimuli. Pashler's letters satisfy the criterion of superfamiliarity, but different letters and inverted letters are grossly different, so performance has already reached ceiling even for inverted letters. Williams and Simons' fribbles and our novel polygons are subtly different, but the amount of training involved (a single session) does not make these stimuli superfamiliar. In contrast, Alvarez and Cavanagh's (2004) "2"s and "5"s are superfamiliar and subtly different (Wang et al., 1994). Familiarity resulted in enhanced change detection in their study. Finally, Buttle and Raymond (2003) found that change detection for masked faces was better when the faces were famous, but not when the faces had recently acquired familiarity. Superfamiliarity with subtly different stimuli makes the stimuli subjectively more distinctive from one another, allowing a change to be more reliably detected. Whether this reflects a genuine capacity change in VWM is a debatable question for future research.

To summarize, by training subjects on random polygons for a single session, we found that visual working memory for polygons was moderately enhanced by training, but the training effect was not specific to the trained shapes. We suggest that familiarity with visual objects has a limited role in affecting online, working memory performance. Future studies should test boundary conditions in which long-term familiarity enhances working memory performance.

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Manuscript received October 2004
Manuscript accepted March 2005

APPENDIX

Hit (detecting a change) and false alarm rates observed in Experiment 3

Measure	*Training*				*Testing*	
	Epoch 1	*Epoch 2*	*Epoch 3*	*Epoch 4*	*Novel*	*Femiliar*
Hit rate	.55	.56	.64	.63	.69	.67
False alarm	.19	.16	.23	.21	.56	.20