Implicit Learning and Memory for Random Visual Noise

Avi M. Aizenman[1], Jason M. Gold [2], & Robert Sekuler[1]
[1]Brandeis University, Waltham MA & [2]Indiana University, Bloomington IN

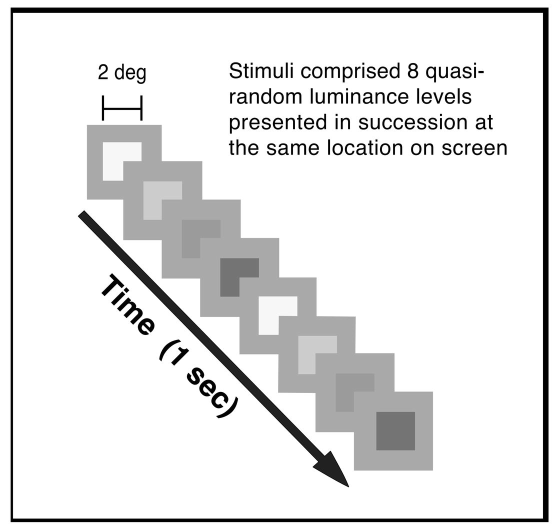
INTRODUCTION

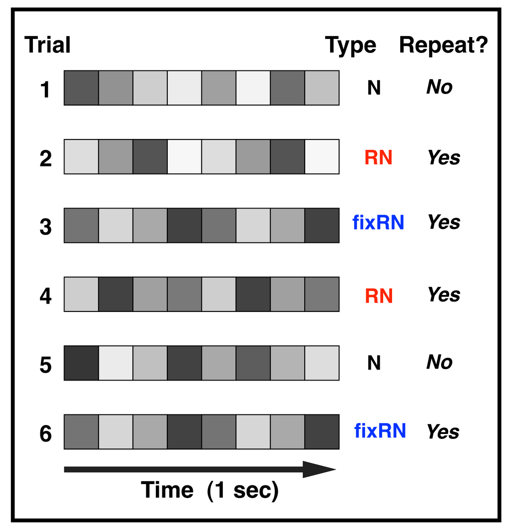
BACKGROUND In a recent study of auditory learning, subjects demonstrated a striking ability to detect when a brief random sample of white noise was repeated immediately after its initial occurrence[1]. Moreover, when the same exemplar of repeated noise was interspersed multiple times among other, random noise stimuli, subjects' ability to detect the repetition of the consistent exemplar showed rapid and sustained improvement.

RATIONALE Comparisons of auditory and visual memory often produce conflicting results[2,3,4]. So we wanted to determine whether rapid learning of repetitions within random auditory stimuli had counterparts in the visual domain. To do this, we devised visual stimuli analogous to those used for auditory learning, and deployed these stimuli in a task modeled closely on that of the auditory study[1].

EXPERIMENT ONE

TASK Stimuli were one-second long sequences of quasi-random luminances presented at 8 Hz to the same location on a display. Subjects judged whether the sequence of four luminances in the first 500 msec repeated identically in the second 500 msec





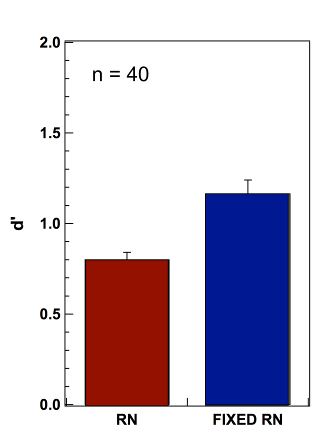
Three different sequence types were randomly intermingled:

N (Noise) –Random luminance levels that do not repeat throughout the trial (50% of all trials)
RN (Repeated Noise) – Luminance levels repeat identically half way through the trial (25% of all trials)
fixRN (fixed Repeated Noise) – A particular exemplar of RN that that was presented multiple random times throughout a block of trials (25% of all trials)

Any unique fixRN sequence was maintained throughout a 200-trial block, but a new fixRN sequence was generated for each block and subject. Subjects received feedback after each response.

Random luminances came from a Gaussian distribution whose mean was the same as the display background (25 cd/m^2); values were censored at ±2 SD.

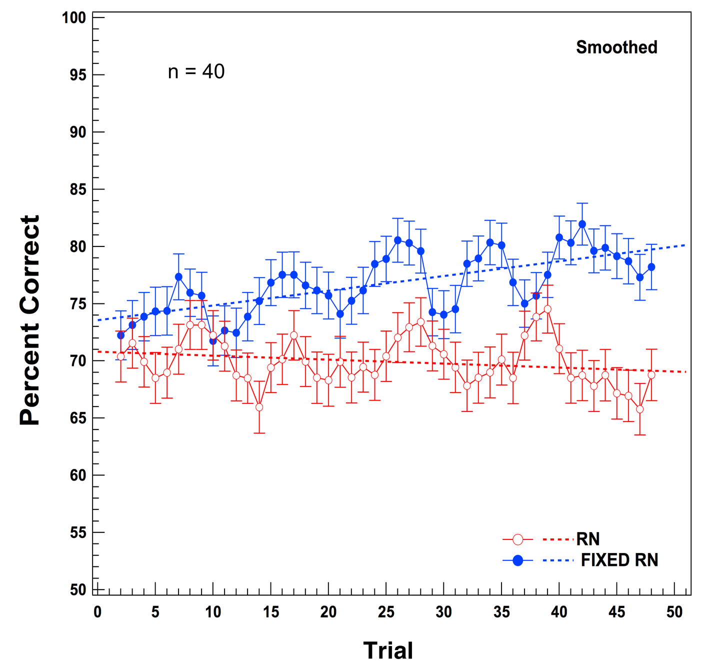
Performance is better when the same sequence recurs



We used d' to compare performance for fixRN and RN stimuli. This measured subjects' success in discriminating between (i) a stimulus on which the first four luminances repeated, and (ii) a stimulus on which they did not repeat. d' for RN was computed as z(hits RN)-z(false alarms **N**); d' for fixRN was computed as z(hits fixRN) – z(false alarms **N**).

d' was significantly higher for fixRN trials than for RN trials. Encountering the same fixRN exemplar on multiple occasions throughout a block of trials enhanced sensitivity to that fixRN exemplar.

Performance improves with multiple encounters with a fixRN

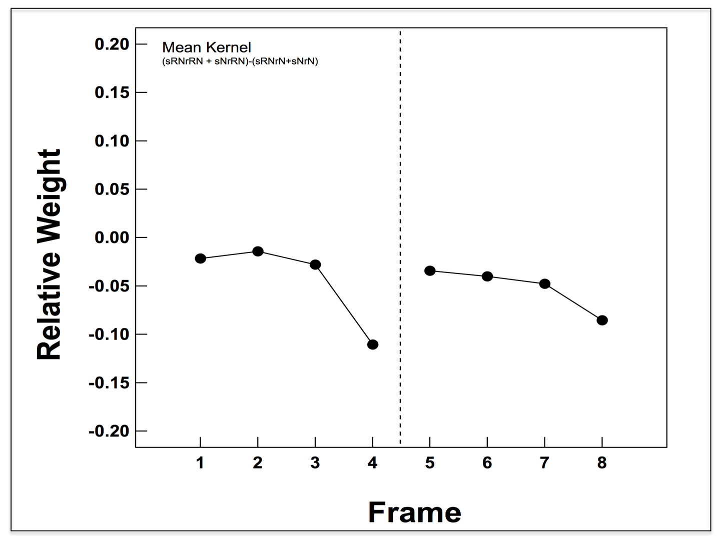


To evaluate trial-by-trial changes in performance for RN and fixRN stimuli, we calculated and smoothed percent correct values within each block of trials (50 for each stimulus type).

Performance with RN stimuli did not change significantly over a block of trials (p>.12). In contrast, performance with the block's fixRN stimulus improved significantly across trials (p<.001).

Reverse Correlation reveals subjects' strategy

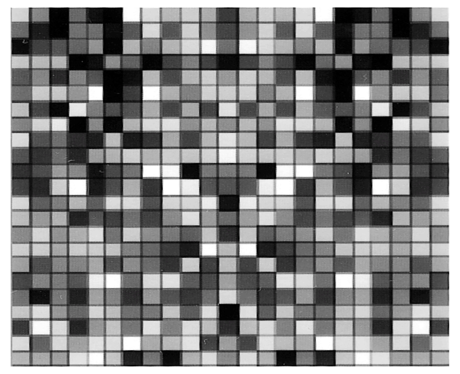
We used reverse correlation[5] to characterize the strategy that subjects adopted when judging whether the first four luminances repeated or not. Specifically, we correlated the luminance presented on each frame of RN and **N** trials with observers' classification decisions. This estimated the relative weight subjects gave to each frame in the stimulus sequence.



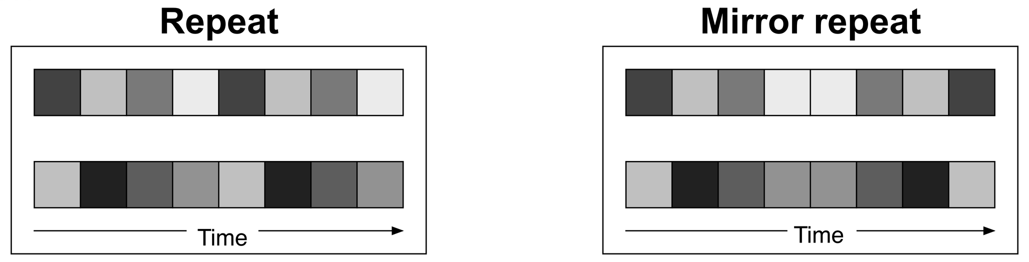
Rather than assigning equal weight to each frame in a sequence, subjects' responses seemed to give extra weight to low-luminance values presented at the end of first and second halves of the 1-sec long stimulus (frames four and eight). That is, subjects seemed to be "looking for" a dark transient just before the middle of the stimulus presentation and at the very end of the stimulus presentation. This might reflect luminance decrements' well-known advantage in visual salience.[7,8]

EXPERIMENT TWO

The human visual system is exquisitely sensitive to mirror symmetry in spatial stimuli, even in stimuli that are otherwise random[6]. However, relatively little is known about sensitivity to mirror symmetry in the **temporal** domain.

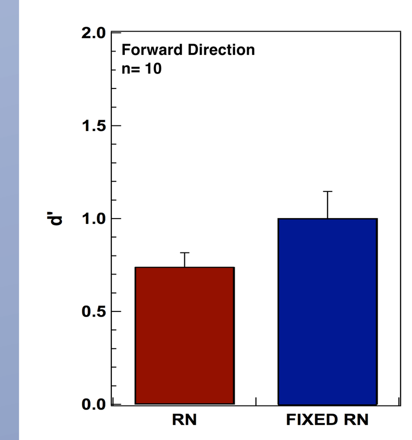


Adapting the methods of Experiment One, we generated versions of RN and fixRN stimuli in which the first four luminances repeated, but did so in reverse (mirror) order.



Ten subjects were tested under the same conditions as in Experiment One; ten other subjects were tested with mirror-symmetrical equivalents to Experiment One's stimuli.

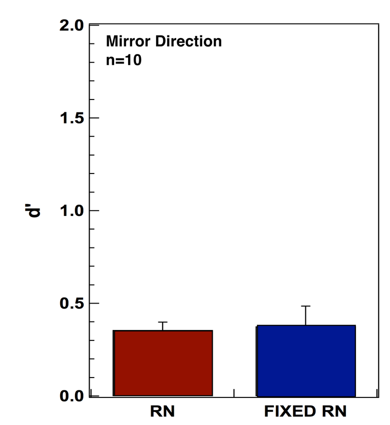
Temporal mirror symmetry is difficult to detect



Subjects tested with the same non-mirror conditions as in Experiment One produced the same result: better performance with fixRN stimuli than with RN stimuli.

Subjects tested with **mirror** repeating stimuli performed slightly above chance, but performed equally with fixRN and RN stimuli.

These results represent a considerable reduction in visual sensitivity to stimuli that are mirror symmetric in the temporal domain.



CONCLUSIONS

1. As was found with sequences of random auditory noise[1], our subjects were able to reliably recognize when the first and second halves of rapidly-presented, random luminance sequences were identical copies of one another.
2. Multiple encounters with a consistent fixRN sequence boosted sensitivity to the repetition embodied in that sequence. However, unlike auditory noise, learning with visual noise was gradual and relatively modest in size. This difference could reflect the lower dimensionality of our stimuli.
3. The tendency for observers to place greater weight on the middle and final frames may reflect a strategy to deal with temporal uncertainty about the exact time at which the sequence would be repeated.
4. Recognizing a mirror-symmetrical repetition was extremely challenging, and produced performance only slightly above chance.
5. Encountering the same random luminance sequences (fixRN stimuli) on multiple occasions boosted performance despite the potential for massive retroactive and proactive interference from other, similar interspersed stimuli.

SOME NEXT STEPS

1. Some subjects claimed to have exploited an intriguing strategy, generating in their mind's ear auditory sequences that mimicked the rise and fall of our luminance sequences. We are currently testing the efficacy of this unusual strategy, with an eye toward the possibility that memory for temporal sequences in audition and vision share a significant common substrate.[9]
2. Our task may provide a useful platform of experimentation for examining links between forms of memory that seem to operate on different scales: immediate memory for what was seen in just the last 500 msec, and memory that supports longer-term performance improvement that develops over time.

REFERENCES

[1] Agus, Thorpe & Pressnitzer (2010) Rapid formation of robust auditory memories: insights from noise. Neuron, 66, 610–618.
[2] Visscher & Sekuler (2007) Auditory short-term memory behaves like visual short-term memory. PLoS Biology 5, e56;
[3] Lehnert & Zimmer (2006) Auditory and Visual Spatial Working Memory. Mem Cognit, 1080-1090.
[4] Cohen, Horowitz & Wolfe (2009) Auditory recognition memory is inferior to visual recognition memory. PNAS 106, 6008-6010.
[5] Eckstein & Ahumada (2002) Classification Images: A tool to analyze visual strategies. Journal of Vision, 2. doi: 10.1167/2.1.i
[6] Barlow & Reeves (1978). The versatility and absolute efficiency of detecting mirror symmetry in random dot displays. Vision Res 19, 783-786.
[7] Blackwell (1946) Contrast thresholds of the human eye. Journal of the Optical Society Am 36, 624-643.
[8] Chubb, Landy & Econopouly (2004) A visual mechanism tuned to black. Vision Res 44 3233-3332.
[9] Guttman, Gilroy & Blake (2005) Hearing what the eyes see. Psychological Science, 16, 228-235.

Acknowledgments. Supported in part by grants from AFOSR and NIMH. We thank Abigail Noyce and Sylvia Guillory for excellent suggestions. Correspondence: vision@brandeis.edu