Cognition 147 (2016) 113–126

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Gift from statistical learning: Visual statistical learning enhances memory for sequence elements and impairs memory for items that disrupt regularities

Sachio Otsuka *, Jun Saiki

Graduate School of Human and Environmental Studies, Kyoto University, Kyoto, Japan

ARTICLE INFO

Article history:
Received 11 March 2015
Revised 19 October 2015
Accepted 11 November 2015

Keywords:
Statistical learning
Memory facilitation
Forgetting
Recognition memory

ABSTRACT

Prior studies have shown that visual statistical learning (VSL) enhances familiarity (a type of memory) of sequences. How do statistical regularities influence the processing of each triplet element and inserted distractors that disrupt the regularity? Given that increased attention to triplets induced by VSL and inhibition of unattended triplets, we predicted that VSL would promote memory for each triplet constituent, and degrade memory for inserted stimuli. Across the first two experiments, we found that objects from structured sequences were more likely to be remembered than objects from random sequences, and that letters (Experiment 1) or objects (Experiment 2) inserted into structured sequences were less likely to be remembered than those inserted into random sequences. In the subsequent two experiments, we examined an alternative account for our results, whereby the difference in memory for inserted items between structured and random conditions is due to individuation of items within random sequences. Our findings replicated even when control letters (Experiment 3A) or objects (Experiment 3B) were presented before or after, rather than inserted into, random sequences. Our findings suggest that statistical learning enhances memory for each item in a regular set and impairs memory for items that disrupt the regularity.

1. Introduction

How do we memorize events (e.g., objects and scenes) in natural environments in our daily life? Previous studies in psychology have proposed that some strategies improve memory (e.g., Atkinson, Atkinson, Smith, Bem, & Nolen-Hoeksema, 2000; Baddeley, Eysenck, & Anderson, 2009). Here, we present a different perspective on improving memory, based on learning statistical regularities (i.e., statistical learning) without awareness. Most studies of statistical learning to date have focused on memory for structured sequences or aggregates. However, what about memory for each item in a structured sequence and inserted distractors that disrupt the regularity? The goal of this study is to demonstrate that simple observation of sequences influences not only learning statistical regularities but also the memory of each element and inserted distractors.

Statistical learning can be defined as the extraction of systematic regularities or patterns embedded in a continuous stream of stimuli. Statistical learning has been demonstrated in young infants by using a sequence of nonsense syllables (Saffran, Aslin, & Newport, 1996). In later years, statistical learning was examined in the visual domain. Fiser and Aslin (2001, 2002) extended auditory statistical learning to visual spatial configuration and temporal structure in adult participants. In a typical experiment on visual statistical learning (VSL), participants viewed a stream of items with embedded triplets (i.e., the same three items consistently appeared in the same order, such as ABC). Participants were subsequently given a two-alternative forced-choice (2AFC) familiarity test. In each test trial, participants judged the relative familiarity of two types of sequences based on the familiarization phase. One test sequence consisted of triplets that were presented in the stream (e.g., ABC, DEF, GHI, and JKL). The other sequence was a foil constructed with items of three different triplets (e.g., AEI, DHL, GKC, and JBF). The results showed that participants correctly discriminated the triplets as more familiar than the impossible foils, suggesting VSL based on temporal structure. In the 2AFC familiarity test, because all items in both the familiar and foil triplets had been presented with the same frequency in the familiarization phase, familiarity judgments reflected memory for sequences, not for each individual item.

The purpose of this study is to examine whether learning statistical regularities influences memory of each constituent element of

* Corresponding author at: Faculty of Culture and Information Science, Doshisha University, 1-3 Tatara Miyakodani, Kyotanabe-shi, Kyoto-fu 610-0394, Japan.

E-mail address: sotsuka@mail.doshisha.ac.jp (S. Otsuka).

http://dx.doi.org/10.1016/j.cognition.2015.11.004
0010-0277/

triplets and distractors inserted into them. As described above, most VSL studies have focused on familiarity of triplets or aggregates, such as chunks and community structure for constituents that co-occur in the temporal domain (Otsuka, Nishiyama, Nakahara, & Kawaguchi, 2013; Schapiro, Rogers, Cordova, Turk-Browne, & Botvinick, 2013). Do statistical regularities influence processing of each element and distractor positively or negatively? To our knowledge, few studies have focused on individual triplet elements except for Barakat, Seitz, and Shams (2013). They presented participants with five pairs of shapes, 150 times each in the exposure phase, and examined the effect of statistical learning on the internal representations of individual stimuli from the pairs. Performance on a rapid serial visual presentation (RSVP) task and a 2AFC target detection task was better for the predicted items (i.e., items in position 2 of each pair) than that for the predictive item in position 1, even when contextual information was not shown in the test phase. Although Barakat et al. (2013) demonstrated that statistical learning influenced the processing of individual elements of pairs, it is unclear whether statistical learning facilitates memory for each individual item from structured sequences.

Research on memory and attention has reported that memory for items presented in the unattended channel is diminished on explicit memory tests such as recognition and recall. In an early study on this issue, Baddeley, Lewis, Eldridge, and Thomson (1984) examined the effects of divided attention (e.g., card sorting or repeating the digits) both on encoding and retrieval using free-recall, cued-recall, and recognition memory tests, and showed that divided attention during encoding decreased performance on all memory tests. The subsequent studies that examined the role of attentional resources in memory encoding demonstrated that selective attention to a stimulus enhances long-term memory for the item, typically by using a dual-task paradigm (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Iidaka, Anderson, Kapur, Cabeza, & Craik, 2000). In addition, Zhao, Al-Aidroos, and Turk-Browne (2013) demonstrated that attention is captured by learned statistical regularities. In their experiment, participants observed displays consisting of four black shapes presented in four locations (top, bottom, left, and right of a central fixation) in the familiarization phase. The stream in one location was structured, whereas the streams in the three remaining locations were random. In the structured sequence, the nine shapes were presented as three triplets (e.g., ABC, DEF, and GHI). In each random stream, the nine shapes were not presented as triplets. Sometimes, a task-relevant visual search display was presented in random positions of the sequences. Each visual search display contained one target and three distractors in the same location as the four streams. The results showed that visual search reaction times (RTs) were shorter for targets presented in the structured positions than in the random positions. Although the streams of visual shapes were unrelated to the visual search task, items shown in the location of the structured stream were given attentional priority. This finding indicates that attention is biased toward the locations of regularities without awareness. In addition, Zhao et al. (2013) demonstrated that attention is captured by visual features (i.e., color and orientation) that have statistical regularities.

Based on the previous studies of VSL and memory, we hypothesized as follows: learning regularities promotes encoding of each element consisting of structured sequences by attentional capture compared to that consisting of random sequences, leading to the enhancement of memory performance in the subsequent recognition memory test. More importantly, although the tests used in most VSL studies, such as the 2AFC familiarity judgment (or visual search, as in Zhao et al., 2013), clearly contain contextual information presented during the familiarization phase, there is no information about regularities in a recognition memory test because each stimulus is presented one at a time (not as a triplet). In this case, participants must decide whether the presented item was shown in the familiarization phase. Thus, our experimental procedure focuses on the familiarity of each triplet element without any temporal cues.

In addition, we examined whether statistical learning impairs memory for items that disrupted regularity. Campbell, Zimerman, Healey, Lee, and Hasher (2012) presented younger and older adults with a sequence of red and green object triplets. Participants performed a 1-back task for objects in one of the colors and so had to pay attention to either red or green sequences. Younger adults learned the statistical regularities for attended sequences, but not for irrelevant (unattended) sequences. In contrast, older adults showed a VSL effect for both attended and unattended sequences, suggesting that younger adults could inhibit information about task-irrelevant regularities. Also, memory inhibition research has shown that people can inhibit words and objects voluntarily or involuntarily (e.g., Anderson, Bjork, & Bjork, 1994; Anderson & Green, 2001; Hertel & Calcaterra, 2005; Kim & Yi, 2013). Thus, we predict that irrelevant and unpredictable information about regularity is degraded during statistical learning without awareness, leading to memory impairment for items that disrupted regularity in the recognition memory test. That is, sufficiently activated elements from structured triplets should compete with the unpredictable items inserted into structured sequences.

In contrast, recently, Kim, Lewis-Peacock, Norman, and Turk-Browne (2014) showed that prediction error affected memory performance for the mispredicted items while memory for unpredictable items did not decrease. In their experiment, participants viewed a continuous stream of faces and natural scenes containing triplets. In each triplet, the first two context elements, "A" and "B", were from one category, and the third element "C" was from the other category (e.g., A and B were faces, and C was a scene). The first two context elements were repeated later in the stream, but were followed by a novel final element "D" from the same category (e.g., A, B, and D were faces). There were three types of old items in the subsequent memory task for elements: the final elements from the initial triplet (C) and repeated triplet (D), and control items (X) presented before the context elements (i.e., inserted into the stream between the triplets). Their results showed that the high-confidence hit rate for C elements was lower than that for D elements, and was marginally lower than that for X items, indicating that memory for elements is impaired when they are mispredicted. However, in Kim et al.'s (2014) study, context elements were only repeated twice. Therefore, participants might have decided that an item D was a new triplet element in the "ABD" triplet, and not a distractor element that disrupted regularities. In this case, associative novelty or prediction errors will promote encoding of items inserted into structured sequences (e.g., Kumaran & Maguire, 2009; Lisman & Grace, 2005), leading to enhanced memory performance for the inserted items. In addition, it is possible that, in accordance with attentional capture due to statistical learning (Zhao et al., 2013), recognition memory for items inserted into structured sequences will also be enhanced by attentional allocation to "structured" rather than "random" sequences. Thus, it is unclear whether memory for items inserted into triplets is enhanced or impaired by statistical learning after triplets have been sufficiently learned (i.e., in the last part of the familiarization phase).

In summary, we tested the following hypotheses in this study: (1) If increased attention induced by statistical learning promotes encoding of elements themselves, recognition memory performance will be higher for elements that were in structured versus random sequences, even though they were presented with equal frequency. (2) If statistical learning inhibits unpredictable stimuli