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Memory for syntax despite amnesia

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Abstract

Syntactic persistence is a tendency for speakers to reproduce sentence structures independently of accompanying meanings, words, or sounds. The memory mechanisms behind syntactic persistence are not fully understood. Though some properties of syntactic persistence suggest a role for procedural memory, current evidence suggests that procedural memory (unlike declarative memory) does not maintain the abstract, relational features that are inherent to syntactic structures. To evaluate the contribution of procedural memory to syntactic persistence, patients with anterograde amnesia and matched control speakers (a) reproduced prime sentences with different syntactic structures; (b) reproduced 0, 1, 6, or 10 neutral sentences; (c) described pictures that elicited the primed structures spontaneously; and (d) made recognition judgments for the prime sentences. Amnesic and control speakers showed significant and equivalent syntactic persistence, despite the amnesic speakers' profoundly impaired recognition memory for primes. Syntax is thus maintained by procedural memory mechanisms, revealing that procedural memory is capable of supporting abstract, relational knowledge.

Speakers often produce sentences using syntactic structures that they have recently spoken or heard. For example, speakers who produce or understand a sentence with a *prepositional dative* structure like "The governess made a pot of tea for the princess" are prone to describe a subsequent unrelated event with another prepositional dative structure, like "The boy is handing the paintbrush to a man." But if speakers initially produce or understand a sentence with a *double-object* structure like "The governess made the princess a pot of tea," they are more likely to describe the subsequent event with another double-object structure, like "The boy handed the man the paintbrush."

This effect is known as *syntactic persistence* or *structural* or *syntactic priming* (for recent reviews, see Ferreira & Bock, 2006; Pickering & Ferreira, in press). Syntactic persistence has been observed in laboratory settings (Bock, 1986), controlled dialogue (Branigan, Pickering, & Cleland, 2000), natural discourse (Szmrecsanyi, 2004, 2005), in different languages (Hartsuiker & Kolk, 1998b) and modalities (Cleland & Pickering, 2006), in children (Huttenlocher, Vasilyeva, & Shimpi, 2004; Thothathiri & Snedeker, in press), and even from one of a bilingual speaker's languages to the other (Hartsuiker, Pickering, & Veltkamp, 2004; Loebell & Bock, 2003). In certain paradigms (including the one used here), syntactic persistence is sensitive specifically to syntactic structure, rather than conceptual, lexical, or phonological information (Bock, 1986, 1989; Bock & Loebell, 1990; Bock, Loebell, & Morey, 1992).

Syntactic persistence reflects *memory* for abstract syntax, because a prime sentence can only influence target production when some trace of the prime's syntactic structure is preserved in memory. However, the nature of the memory processes that underlie syntactic persistence is not well known. Generally, memory is divided into two systems: *procedural* and *declarative*. Procedural memory is associated with perceptual fluency and motor skills and with memories that are acquired and tuned through experience, allowing better perception of specific stimuli or execution of specific motor actions. In contrast, declarative memory maintains knowledge of facts and events, and is capable of maintaining memories that are abstract and relational.

Several features of syntactic persistence suggest that it may depend on procedural memory for syntactic knowledge. Procedural memories are resistant to forgetting; likewise, syntactic persistence is resistant to forgetting, surviving undiminished over the comprehension, production, and assessment of ten intervening neutral sentences (Bock, Dell, Chang, & Onishi, 2007; Bock & Griffin, 2000). Declarative memories for complex knowledge, in contrast, typically show consistent decay with time and intervening material. Furthermore, when declarative memory for specific sentences is assessed, sentences that are explicitly remembered are not more likely to cause syntactic persistence, and sentences that cause syntactic persistence are not more likely to be explicitly remembered (Bock & Griffin, 2000). This is consistent with independence between declarative memory and syntactic persistence, implying that the alternative procedural memory system underlies the persistence effect.

A problem with a procedural memory account of syntactic persistence is that there are well-established limitations of procedural memory in dealing with abstract and relational knowledge. Syntax is inherently abstract, in that a particular syntactic structure can never be defined in terms of particular perceptual or motor properties. Syntactic persistence specifically is found even when syntactically similar prime and target sentences share no content words at all (Bock, 1989; Ferreira, 2003). Indeed, syntactic persistence from one language to another demands an abstract basis for it. Syntax is also inherently relational, being defined as arrangements of syntactic categories (noun, verb, etc.). Against these features, with the possible exception of artificial-grammar learning (Knowlton & Squire, 1996), procedural memory has not been implicated in the representation or use of knowledge that is abstract with respect to the perceptual or motor features of experience. Furthermore, prior research has revealed that procedural memory is unable to represent some forms of relational knowledge, such that procedural memory treats experiences involving old elements arranged in new ways as though they were brand new experiences (Ryan, Althoff, Whitlow, & Cohen, 2000). This is problematic for a procedural memory account of syntactic persistence.

In the work described here, we tested patients with *anterograde amnesia* (henceforth *amnesia*) and matched control subjects to provide evidence regarding the memory bases of syntactic persistence. Patients with amnesia have damage to medial-temporal lobe and related brain structures. They show profound impairment in declarative memory, including deficits in recollecting specific events that occurred since their trauma, and in applying knowledge of those events to new behaviors. However, they show preserved procedural or nondeclarative memory, revealing many of the changes in performance that result from previous experience in neurologically intact individuals (for review, see Squire, 1992). If syntactic persistence is intact in patients with anterograde amnesia, it would support a procedural account of syntactic persistence. This outcome would also imply that the comparatively simple procedural memory system is capable of supporting memory for abstract, relational knowledge, widening the reach of procedural memory into complex cognitive domains.

The experimental procedure measured syntactic persistence and in parallel, declarative memory for the syntax and meanings of sentences. The procedure with example materials is shown in Figure 1. Patients and controls participated in a task presented as a test of sentence and picture memory, repeating sentences and describing pictures as ostensible aids to retention. Speakers (a) repeated prime sentences in prepositional dative, double-object dative, passive (*The passerby was jostled by the drunk*), or active (*The drunk jostled a passerby*) structures; (b) repeated 0, 1, 6, or 10 neutral (intransitive or predicate-adjective) structures, (c) extemporaneously described unrelated pictured events that could elicit sentence targets with the same structures as the primes; and then (d) made recognition judgments about probe sentences that were the same or different from the prime sentences. From the participants' perspective, the only tasks were to repeat sentences and describe pictures, indicating for each sentence or picture whether it had occurred previously in the session.

Syntactic persistence was measured in terms of speakers' tendency to use the sentence structures from the primes in their extemporaneous target-picture descriptions. Declarative (recognition) memory was assessed by measuring speakers' accuracy in judging whether probe sentences were the same as prime sentences. If the abstract, relational information underlying syntactic persistence is grounded in procedural memory, then patients with anterograde amnesia should display syntactic persistence to the same extent that matched controls do, despite exhibiting impaired recognition memory for prime sentences.

Method

Subjects

We tested four amnesic patients (Ryan et al., 2000; Ryan & Cohen, 2004) and four matched controls. Amnesic patients were three men and one woman. No control reported previous head injury or loss of consciousness. Table 1 reports subject characteristics. Every speaker was tested on 256 prime-target-probe sentence sequences, spread across eight sessions each separated by at least one month.

Procedure

An experimental session contained 32 blocks. Each block included one prime-target-probe sequence embedded within 14 sentence and picture trials. Prime-target-probe sequences began with a screen instructing subjects to listen to and repeat an upcoming sentence. After auditory presentation and repetition of the sentence, the experimenter advanced to a screen that prompted recognition judgment ("Have you said that sentence before in this session?"). Target trials began with a screen instructing subjects to look at and describe a subsequent picture. The experimenter then advanced to the picture. After the picture description, the experimenter advanced to a screen prompting a recognition judgment ("Have you seen that picture before in this session?"; note that recognition memory for pictures is uninformative and is not reported, but was included to make picture and sentence trials similar in structure). Probe trials had the same format as prime trials.

The block structure is illustrated in Figure 1. Every block began with a filler picture trial (which proceeded exactly like the target picture trials). This was followed by a sequence of eleven sentence trials (each of which proceeded exactly like the prime trial), one of which was the prime sentence. Next followed the target picture trial, and then the block concluded with a probe sentence trial. Lag was manipulated in the set of 11 sentence trials by positioning the prime first (Lag 10), fifth (Lag 6), tenth (Lag 1), or last (Lag 0) in the sequence. After every trial, the subject's button-box response initiated the next trial. All spoken and manual responses were recorded.

Materials

Materials included 20 filler pictures, 32 pairs of prime sentences, 32 target pictures, 32 probe sentences, and 96 neutral filler sentences. Half of the prime pairs were transitive structures and half were dative. Transitive pairs comprised an active and passive counterpart, and dative pairs a prepositional dative and double-object counterpart. Half the target pictures showed a nonhuman acting on a typically human entity, and tended to elicit transitive (both active and passive) descriptions. The other half showed a human presenting or delivering an inanimate object to an animate recipient, eliciting dative (prepositional and double object) sentences. Of the 32 probe sentences in a session, eight were identical to the prime sentence from the same block, eight had a different syntactic structure but the same meaning, eight had a different meaning but the same structure, and eight had both a different structure and meaning. Meaning-distinct probes were created by reversing relations within sentences, changing single arguments, and similar tactics. Neutral sentences were intransitive or predicate-adjective structures with single arguments. All materials were digitized and presented by computer. Two additional pictures and two sentences were used for instruction and demonstration at the beginning of each experimental session.

Half of the 32 sequences from each session alternated active and passive structures and half alternated prepositional and double-object datives. The transitive and dative blocks themselves alternated, so that a block sequence might test an active, prepositional dative, passive, double object. In every session, eight prime sentences occurred as prepositional datives and eight others as double objects, two per lag. An analogous design was used for transitive primes. Across eight sessions, both forms of every prime sentence were presented four times, once per lag, and each kind of probe for a prime sentence was presented twice, counterbalanced in a fashion that was unconfounded with the other manipulations. Except for 12 repeated filler pictures and the identical probe sentences, every stimulus was unique within a session.

Coding and analysis

To assess syntactic persistence, prime-sentence repetitions and target-picture descriptions were transcribed from tape and coded as passive, active, prepositional dative, or double-object structures. Trials where the prime was not reproduced verbatim (except for minor meaning- and syntax-preserving deviations) or where targets were not one of the four coded structures were discarded. Coding was performed as in previous work (Bock & Griffin, 2000); 31% of trials included exuberant or deviant productions and so could not be coded. All significant effects reached the .05 level or better. For readability, we report back-transformed means and mean differences, and proportions are reported as percentages. Recognition judgments on probe sentences were coded as hits and misses (for identical probes) and false alarms and correct rejections (for distinct probes). These were converted into discriminability (d') measures for each subject and lag. Hit rates of 1 were adjusted to $[1 - 1 / 2n]$ to allow d' computation (Macmillan & Creelman, 1991).

The measure of syntactic persistence was the proportion of *target* structures that speakers produced out of all target and *alternative* structures. Target structures were defined as the generally less common form of each sentence type (passives and prepositional datives), and alternative structures as the generally more common forms (actives and double objects). Target-structure proportions were computed separately for each subject group (amnesic, control), sentence type (transitive, dative), lag (0, 1, 6, and 10), and prime type (target primed, alternative primed), arcsine-transformed (Winer, 1971), and entered into mixed-design analyses of variance (ANOVAs) by subjects ($F1$) and, for priming measures, items ($F2$). Grouping was between subjects and within items, sentence type was within subjects and between items, and prime type and lag were within both subjects and items. Six items

were excluded from the items analyses because of missing values. We report confidence-interval halfwidths derived from ANOVA results (Loftus & Masson, 1994; Masson & Loftus, 2003). Recognition memory was assessed by entering d' measures into a mixed ANOVA with factors lag (within subjects) and group (between subjects). We report proportion of variance accounted for with partial eta squared (η_p^2) and probability of replication (p_{rep}) when appropriate (Killeen, 2005).

For the standardized analysis (Figure 4), syntactic persistence scores were computed for each subject by subtracting the arcsine transformed proportion of target structures produced after alternative-structure primes from the arcsine transformed proportion of target structures produced after target-structure primes. This was done for each condition in the persistence design. Means and standard deviations of controls' persistence scores within each condition were used to compute z-scores for each patient's syntactic persistence score within that condition. An analogous procedure yielded recognition memory z-scores. Negative values indicate impairment relative to controls; values close to zero indicate performance similar to controls.

Results

Figure 2 shows the back-transformed proportion of target structures that amnesic and control speakers produced as a function of lag and prime sentence structure (target or alternative structure). Overall, speakers produced 7.4% more target structures when target structures were primed (filled symbols) compared to when alternative structures were primed (open symbols), $F(1,6) = 11.0$, $CI = \pm 5.5\%$, $\eta_p^2 = .65$; $F(1,24) = 14.9$, $CI = \pm 3.7\%$, $\eta_p^2 = .38$. Amnesics produced fewer target structures overall than controls (23% vs. 54%), $F(1,6) = 16.8$, $CI = \pm 18.8\%$, $\eta_p^2 = .74$; $F(1,24) = 141$, $CI = \pm 6.4\%$, $\eta_p^2 = .85$. Markedly reduced rates of prepositional dative and passive production in clinical populations have been observed in at least one other investigation (Hartsuiker & Kolk, 1998a); the source of these differences is not understood. Persistence nonetheless occurred both in amnesic speakers (a 7.7% difference) and in controls (a 7.1% difference) and, critically, to similar degrees: The interaction between population and prime type was not significant, $F(1,6) < 1$, $CI = \pm 7.7\%$, $\eta_p^2 = .003$; $F(1,24) < 1$, $CI = \pm 7.1\%$, $\eta_p^2 = .028$. For amnesics, persistence tended to increase monotonically with lag, whereas for controls it was not evident at Lag 6. However, the interaction between population, prime type, and lag was not significant, $F(3,18) < 1$, $CI = \pm 13.2\%$, $\eta_p^2 = .081$; $F(3,72) < 1$, $CI = \pm 12.5\%$, $\eta_p^2 = .007$. Most telling is that persistence was evident in both groups at the longest lag (as revealed by a simple main effect of prime type within the Lag 10 condition that was marginally significant by subjects, $F(1,18) = 4.3$, $p < .06$, and significant by items, $F(1,72) = 4.1$), consistent with its basis in procedural memory.

Figure 3 shows discriminability scores for recognition of prime sentences at each lag. Memory for prime sentences was significantly poorer for amnesics (overall d' of 0.93) than controls (overall d' of 1.81), $F(1,6) = 3.68$, $CI = \pm 0.71$, $\eta_p^2 = .61$. Amnesics' memory impairment was evident at every lag. Figure 4 reveals syntactic persistence and memory performance for each amnesic patient, standardized in terms of controls' performance. In terms of standard scores, each amnesic exhibited sizable recognition-memory impairments at the same time as three of the four exhibited intact syntactic persistence. (The patient who did not exhibit persistence had damage extending to more frontal brain regions, compared to the other patients, perhaps hinting at a neural locus of the persistence effect.) Across patients, the mean recognition memory standardized score (-1.81) was significantly different from the mean syntactic persistence standardized score (0.11), $t(3) = 3.26$, $CI = \pm 1.87$, $\eta_p^2 = 0.35$, $p_{rep} = .890$.

Discussion

Patients with amnesia exhibited syntactic persistence from prime sentences. The magnitude of persistence observed for the amnesic patients was the same as for memory-unimpaired subjects, despite the patients' significantly worse memory for the meaning of prime sentences. We discuss these results with respect to three issues: The nature of syntactic persistence, the reach of procedural memory, and the cognitive specialization of language.

The nature of syntactic persistence

These results suggest that syntactic persistence, and conjecturally, the memory representation of syntactic knowledge, is rooted in procedural and not declarative memory. The procedural basis of syntactic persistence is predicted directly by specific models of the acquisition and use of syntax (Chang, Dell, & Bock, 2006) that were designed to explain syntactic persistence (among other phenomena). It is also consistent with the *alignment* approach of Pickering and Garrod (2004), which treats syntactic persistence as automatic. Other models designed to explain syntactic persistence (e.g., Pickering & Branigan, 1998) make no specific claims about whether the knowledge structures underlying persistence are grounded in declarative or procedural memory, but emphasize lexical components of persistence that are more likely to be associated with explicit, declarative effects.

Consistent with evidence that recognition memory for sentences rests on memory for the *meanings* of sentences (Sachs, 1967), control subjects rejected foils in the present experiment more accurately when they differed from primes in meaning (with a false-alarm rate of 29.0%) than when they differed from primes only in syntactic structure (with a false-alarm rate of 59.2%), $t(3) = 6.49$, $CI = \pm 14.8\%$, $\eta_p^2 = 0.93$, $p_{rep} = .946$. Thus, by dissociating syntactic persistence from recognition memory, these results also imply that declarative memory for syntactic structure (if any) is different from procedural memory for syntactic structure. Many general approaches to language (Bates & MacWhinney, 1982) as well as specific theories of syntactic structure (e.g., Goldberg, 1995) claim that syntax is tightly related (if not fully reducible) to meaning-level knowledge. These results contradict such approaches. Instead, the data fit well with accounts of language function that distinguish content and process, placing the former in the declarative memory system and the latter in the procedural (e.g., Ullman et al., 1997).

The reach of procedural memory

To the extent that the syntactic knowledge underlying syntactic persistence is maintained in procedural memory, it alters current conceptions of the representational and computational capabilities of procedural memory. First, the procedural basis of syntactic persistence implies that procedural memory can operate on fully abstract knowledge, as the prime sentences that influenced target production did not share any distinctive words with those target sentences. The upshot is that perceptual and motor knowledge, which are by nature rooted in concrete experience, cannot explain such persistence and so cannot explain this procedural memory effect. Second, because the syntactic knowledge that underlies syntactic persistence is inherently relational, it suggests that procedural knowledge can indeed support certain forms of relational knowledge. A likely reconciliation of previous (Ryan et al., 2000) and current observations is that relational knowledge called on by specialized processing systems, such as the syntactic processing system, can be stored and maintained in procedural memory.

Related evidence regarding the maintenance of abstract knowledge in procedural memory comes from artificial grammar learning. For example, Knowlton and Squire (1996) showed that after patients with amnesia were exposed to letter sequences governed by an unstated

system of rules (an artificial grammar), they showed better processing of new letter sequences, even when the new sequences shared no letters at all with the original ones. These results suggest too that procedural memory can operate for abstract knowledge (the rules of the artificial grammar). However, the processing basis of artificial grammar is highly controversial, with arguments that it may reflect certain relatively concrete knowledge structures (Redington & Chater, 1996). By providing a convincing demonstration that procedural memory in fact can underlie fully abstract knowledge, the present results thus support the original characterization of the artificial grammar results.

The cognitive specialization of language

The observations reported here cast a different light on the ‘special’ status of language. That is, a classic argument about language is whether the cognitive basis of linguistic processing differs fundamentally from the cognitive basis of other skills and abilities. Procedural systems are dedicated to the skills they underlie; the procedural systems that underlie reading words, recognizing objects, or riding bikes all differ from one another and have been sculpted by a combination of innate and experience-based forces to specialize in executing each of those skills. By virtue of its procedural nature, syntactic knowledge evidently also has this specialized status. At the same time, procedural systems operate by common principles and are in important respects a single collection of systems. This is a different way of viewing the language faculty as a ‘new machine built from old parts’ (Bates, 1999). Overall, we conclude that the core knowledge underlying our syntactic abilities — one of the most creative capacities known in nature, and one that is commonly thought to depend on advanced and flexible intelligent functioning — is shaped by a specialized system of basic memory mechanisms found in even the simplest of organisms.

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Figure 1. One block of the procedure. “S” = subject. Prime-target sequence in boldface. Figure illustrates prepositional dative prime, different-syntax-different-meaning foil, and persistence lag of 6. Subjects make recognition judgments for every picture (with the query, “Have you seen that picture before in this session?”) and sentence, as shown for the probe sentence.

Figure 2.

Syntactic persistence: Back-transformed proportions of target structures produced by control subjects (dashed lines) and amnesic subjects (solid lines) after target-structure (filled symbols) and alternative-structure (open symbols) primes, with 0, 1, 6 or 10 intervening neutral sentences. Error bars illustrate 95% confidence interval of the difference collapsed across lag.

Figure 3. Recognition memory: Discriminability (d') scores for control and amnesic subjects with 0, 1, 6 or 10 intervening neutral sentences. Error bars illustrate 95% confidence intervals collapsed across lag.

Figure 4.

Syntactic persistence and recognition memory standardized (z) scores for each amnesic subject, standardized on controls' mean and standard deviation persistence and discriminability scores. Error bars show 95% confidence-interval halfwidth of the difference between memory types.

Subject characteristics

Table 1

Designator	Etiology	Age	Yrs of Educ	WAIS-R	WMS-R
A1	Allergic reaction to contrast agent, causing extended period of status epilepticus	54	9	90	54
A2	Removal of third-ventricle tumor with surgical complications	50	18	103	56
A3	Rupture and surgical repair of anterior communicating artery aneurysm	53	18	131	66
A4	Rupture and surgical repair of anterior communicating artery aneurysm	45	12	81	50
C1	—	53	13	102	105
C2	—	50	16	110	102
C3	—	57	16	118	113
C4	—	45	12	100	100

Note. Patients and matched controls have analogous designators. Etiology = cause of amnesia in patients. Yrs of Educ = total education in years. WAIS-R = intelligence, measured by Weschler Adult Intelligence Scale-Revised. WMS-R = delayed memory, measured by Weschler Memory Scale-Revised.