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## Declarative/Procedural Model (DP)

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The Declarative/Procedural (DP) model posits that both first and second language (L1 and L2) depend on two long-term memory systems in the brain: declarative and procedural memory (Ullman, 2001b, 2004, 2005). Because the computational, anatomical, physiological, molecular and genetic

substrates of these systems are well studied in both animals and humans, this theoretical approach generates a wide range of well-motivated, specific and testable predictions about the neurocognition of both L1 and L2 that one might have no reason to make based on the study of language alone.

This entry summarizes the two memory systems and their interactions, presents the basic predictions of the model for first and second language, provides an overview of the evidence, and discusses future directions.

### The two memory systems

The *declarative memory system* underlies the learning, representation, and use of knowledge about facts and events, such as the fact that Kilimanjaro is the highest mountain in Africa, or that you had onion soup for lunch yesterday (Eichenbaum and Cohen, 2001; Squire *et al.*, 2004, Ullman, 2004). The system may be specialized for learning arbitrary bits of information and associating them. Knowledge in this system is learned rapidly, and is at least partly, though *not* completely, explicit – that is, available to conscious awareness.

The hippocampus and other medial temporal-lobe structures learn and consolidate new knowledge, which ultimately depends largely on neocortical regions, particularly in the temporal lobes. Other brain structures play a role in declarative memory as well, including a region in the frontal neocortex corresponding to Brodmann's Areas (BAs) 45 and 47 (within and near classical Broca's area), which underlies the selection or retrieval of declarative memories. (Note that for both the declarative and procedural memory systems, the DP model refers to the *entire* neurocognitive system involved in the learning, representation, and processing of the relevant knowledge, not just to those parts underlying learning and consolidating new knowledge.)

Declarative memory is modulated by various factors (Eichenbaum and Cohen, 2001; Ullman, 2004, 2005; Ullman *et al.*, 2008). Molecular factors include estrogen (higher levels improve declarative memory in women, men, and rodents) and variability in the genes for at least two proteins, BDNF (brain derived neurotrophic factor) and APOE

(apolipoprotein E). Other factors also affect it, including sex (females seem to have an advantage at declarative memory over males), sleep (memory consolidation is improved by sleep), and – of particular interest for the study of second language acquisition – age (declarative memory improves during childhood, plateaus in adolescence and early adulthood, and then declines).

The *procedural memory system* underlies the implicit (non-conscious) learning of new, as well as the control of already-learned, perceptual-motor and cognitive skills, such as typing, riding a bicycle, or video game playing (Eichenbaum and Cohen, 2001; Henke, 2010; Ullman, 2004; Ullman and Pierpont, 2005). It may be specialized, at least in part, for sequences and rules. Learning in the system requires extended practice, though it seems to result in more rapid and automatic processing of skills and knowledge than does learning in declarative memory. Note that the term “procedural memory” is used by the DP model to refer only to *one* implicit non-declarative memory system, *not* to all such systems.

The procedural memory system is composed of a network of interconnected brain structures rooted in frontal/basal-ganglia circuits, including premotor cortex and BA 44 (within Broca’s area) in the frontal cortex. Although procedural memory is generally less well understood than declarative memory, evidence suggests that the neurotransmitter dopamine plays an important role in this system, as do certain genes, including *FOXP2*. Other factors may also affect procedural memory, including age – unlike declarative memory, procedural memory seems to be well established early in life, after which learning and consolidation in this system may attenuate (Ullman, 2005).

These two memory systems *interact* both cooperatively and competitively in learning and processing (Poldrack and Packard, 2003, Ullman, 2004). First, the two systems can complement each other in acquiring the same or analogous knowledge, including knowledge of sequences and rules. Declarative memory may acquire knowledge initially, thanks to its rapid acquisition abilities, while the procedural system gradually learns analogous knowledge, which is eventually processed rapidly and automatically. Second, animal and human stud-

ies suggest that the two systems also interact competitively, resulting in a “see-saw effect.” Thus, the dysfunction of one system may result in enhanced functioning of the other. Along the same lines, estrogen seems not only to improve declarative memory, but also to suppress procedural memory.

### Predictions of the model

According to the DP model, each of the two memory systems plays roles in language analogous to those they play in other domains in animals and humans (Ullman, 2001a, 2001b, 2004, 2005).

In L1, declarative memory underlies all idiosyncratic knowledge in language – that is, the mental lexicon – across linguistic sub-domains (e.g., simple words and their meanings, irregular morphology, syntactic complements). Procedural memory can underlie the rule-governed sequencing of complex forms, again across sub-domains, including phonology, morphology, and syntax (e.g., *walk + -ed*, *the + cat*). Crucially, however, complex forms can *also* be learned and processed in declarative memory, for example as chunks (e.g., “walked,” “the cat”). Thus, complex forms can rely on either memory system. Which one they rely on should depend on various subject-, task- and item-level factors. For example, individuals or groups with superior declarative memory abilities (e.g., women as compared to men), or worse procedural memory abilities (e.g., those with developmental disorders that affect this system, such as Specific Language Impairment, or those with *FOXP2* mutations; Ullman and Pierpont, 2005) should rely more on declarative and less on procedural memory.

The pattern expected for L2 is similar in some respects to that expected for L1 but different in others (Ullman, 2001a, 2005). First, as in L1, lexical knowledge in L2 should be learned in declarative memory. However, the strength of this knowledge should be weaker in later-learned L2 than in earlier-learned L2 or L1: When matched for age, L1 and early L2 learners have had more years of exposure to lexical input than late L2 learners. Moreover, unlike in L1, lexical learning in L2 may be impeded by difficulties with L2 phonology or proactive interference from the L1.

Second, the improvement of declarative memory and possible attenuation of procedural memory during childhood leads to the expectation that complex forms should rely more on declarative and less on procedural memory in later-learned L2 than in L1 or earlier-learned L2. In L1 and even early-learned L2, adult speakers should rely heavily on procedural memory because this system was readily available during childhood learning of the language, and many years of exposure should have allowed for substantial proceduralization. By contrast, adult speakers of later-learned L2 should rely heavily on declarative memory for complex forms because procedural memory may be attenuated in adults, while declarative memory is in its prime; moreover, as compared to age-matched L1 subjects, L2 learners have had fewer years or exposure to the language and thus less opportunity for proceduralization.

Crucially however, proceduralization of the grammar should nonetheless occur in L2, even in adult learners. Although procedural memory is attenuated in adults, it is certainly not afunctional, and indeed procedural learning is well studied in adults. Thus, although L2 grammar should rely heavily on declarative memory (particularly at lower L2 exposure, and especially in later learners), with increasing exposure it should be increasingly proceduralized, and thus increasingly L1-like (contrary to strict versions of the critical period hypothesis). However, the speed and degree of the proceduralization of grammatical abilities should vary substantially as a function of many intrinsic and extrinsic factors, including not only the amount of L2 exposure (i.e., practice with the L2), but also the type of input and the kinds of grammatical rules and relations (some should be easier to proceduralize), as well as intrinsic factors such as sex and genotype.

Note that it is *not* the case that such changes in the relative reliance on the two memory systems are due to any “transformation” of knowledge from one to the other system. The two systems *independently* acquire knowledge, even though knowledge acquired in one system may enhance or inhibit the learning of analogous knowledge in the other. Thus, proceduralization of grammar does *not* constitute the “transformation” of declarative into procedural

representations, but rather the gradual acquisition of grammatical knowledge in procedural memory: this system is increasingly relied on, with an accompanying decrease in reliance on declarative memory.

Finally, although the DP model is similar in some respects to other SLA approaches that refer to “declarative memory” and “procedural memory” or to explicit and implicit knowledge (e.g., DeKeyser, 2003, Paradis, 2004), it also differs from them. In particular, the DP model defines the two memory systems according to their neurocognitive bases, whereas most SLA conceptions of declarative and procedural memory treat them – contrary to the neurocognitive evidence – as isomorphic to explicit and implicit memory, respectively (for further discussion see Morgan-Short and Ullman, 2012; Ullman, 2005).

## Evidence

Here we discuss evidence related to the DP model’s predictions about L2 and its relation to L1. We focus primarily on evidence from Event-Related Potentials (ERPs), whose L2-related findings are more consistent and comprehensive than those from other methodological approaches, such as hemodynamic neuroimaging with PET or fMRI, or neurological studies of adult-onset brain damaged patients. (For more in-depth reviews of all these lines of evidence, see e.g., Abutalebi, 2008; Indefrey, 2006; Kotz, 2009; Morgan-Short and Ullman, 2012; Steinhauer *et al.*, 2009; Ullman, 2001a, 2005.)

In L1, different types of processing difficulties elicit different ERP components. Lexical/semantic processing elicits central/posterior bilaterally distributed negativities (N400s) that often peak about 400 ms after the onset of the word. N400s reflect aspects of lexical/semantic processing, depend at least partly on declarative memory brain structures, and appear to reflect the processing of knowledge learned in declarative memory. In contrast, difficulties in (morpho)syntactic processing often produce two components: first, early (150–500 ms) left-to-bilateral anterior negativities (LANs), which appear to reflect aspects of rule-governed automatic structure-building, and may depend on the procedural memory brain system; and second, late (600

ms) centro-parietal positivities (P600s), which are linked to controlled (conscious) processing and structural reanalysis (and are not posited to depend on procedural memory).

In L2, lexical/semantic processing also elicits N400s, even after minimal L2 exposure – though N400s in L2 learners can be delayed and have reduced amplitudes. This is consistent with the DP model's predictions that L2 is like L1 in depending on declarative memory for lexical acquisition and processing, even though the lexical knowledge may be weaker than in L1. In contrast, L2 differs from L1 in (morpho)syntactic processing, in particular at lower levels of exposure and proficiency. (Proficiency and exposure are generally correlated and difficult to tease apart in L2 studies; following many L2 neurocognitive studies, below we refer only to proficiency levels rather than to both proficiency and exposure.) At lower levels, LANs are typically absent, with subjects instead showing no negativity at all or N400s or N400-like posterior negativities. This is consistent with a lack of reliance on procedural memory for grammar, and a possible dependence on declarative memory instead. However, recent studies have reported LANs in higher proficiency L2, consistent with eventual proceduralization of the grammar. Finally, P600s are generally found in L2, particularly at higher proficiency.

Studies of artificial languages can further elucidate the neurocognition of L2, especially because these languages can be rapidly learned (in the order of hours to days, likely due to their reduced vocabulary and rule inventory) and thus the neurocognition of L2 can be easily compared longitudinally between lower and higher proficiency levels. ERP studies of artificial languages have shown that whereas at lower proficiency adult L2 learners under certain training conditions can show N400s in response to syntactic violations, at higher levels they show a LAN/P600 response, consistent with the expected shift from declarative to procedural memory (Morgan-Short *et al.*, 2012). In an fMRI study of an artificial language (Opitz and Friederici, 2003), adult learners initially depended on the hippocampus and temporal neocortical regions for syntactic processing. Subsequently, activation in these brain structures *decreased* with increasing

proficiency, while activation in BA 44 *increased*. Again, this suggests a switch from declarative memory to procedural memory during L2 learning.

### Summary and future directions

In sum, the DP model is a useful theoretical approach for generating novel specific predictions, and has a fair degree of empirical validity thus far. Yet much remains to be examined. For example, there has been little work on the model's endocrine or genetic predictions in either L1 or L2. Additionally, the model's pharmacological and pedagogical ramifications may prove important for second language learning. Future studies will provide a better understanding of the model and its implications.

**See also:** declarative memory and knowledge, explicit learning, implicit learning, procedural memory and knowledge, psycholinguistics of SLA, semantic processing

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## Depth of processing

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Students can take different approaches when acquiring second language vocabulary. Specifically, they can focus on the sound (phonology), spelling (orthography), or meaning (semantics) of the words. These can be viewed as different levels, or depths, of processing, and the depth of processing has been shown to influence learning and retention ( Craik and Lockhart, 1972). One way that researchers have used to vary processing depth is to give the student an orienting task when exposed to the vocabulary items, with no explicit mention of any future memory test. For example, to elicit orthographic processing, students could judge whether a given word contains a specific target letter, and to elicit semantic processing, students could judge instead the pleasantness of the word. It has been shown that semantic processing leads to better memory than does orthographic processing. More generally, material is learned better with deeper levels of processing.

Although the type of processing that occurs at the time of encoding information influences memory, that is not the only factor of importance. Also critical is the type of processing that occurs at the time of retrieving the information. In fact, it has been shown that a more shallow level of processing at encoding leads to better retention than a deeper level of processing at encoding if the retention test also demands a shallow processing level. To illustrate the importance of such *transfer appropriate*