Towards a unified account of the representation, processing and acquisition of second language knowledge

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This article argues for the need to reconcile symbolist and connectionist accounts of (second) language learning by propounding nine claims, aimed at integrating accounts of the representation, processing and acquisition of second language (L2) knowledge. Knowledge representation is claimed to be possible both in the form of symbols and rules and in the form of networks with layers of hidden units representing knowledge in a distributed, subsymbolic way. Implicit learning is the construction of knowledge in the form of such networks. The strength of association between the network nodes changes in the beginning stages of learning with accumulating exposure, following a power law (automatization). Network parts may attain the status equivalent to 'symbols'. Explicit learning is the deliberate construction of verbalizable knowledge in the form of symbols (concepts) and rules. The article argues for a nonnativist, emergentist view of first language learning and adopts its own version of what could be called a non-interface position in L2 learning: although explicit knowledge cannot turn into implicit knowledge through practice, it is argued that explicit learning and practice often form efficient ways of mastering an L2 by creating opportunities for implicit learning.

I Introduction

The notion of information processing, the topic of this issue of *Second Language Research*, has been common currency in both linguistics and psychology for more than four decades (e.g., Miller *et al*., 1960; Miller and Chomsky, 1963). Theories of language, language use, and language acquisition regard language, in one way or another, implicitly or explicitly, as information that is perceived, encoded, stored and retrieved. The study of second language acquisition (SLA) has so far mainly been conducted by linguists rather than by psychologists. As almost all linguists in the nineteenth and twentieth centuries approached language in terms of symbols and rules, it comes as no surprise that SLA researchers

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adopted a similar view on their explenanda, such as acquisition orders, first language (L1) transfer, fossilization, and mechanisms of knowledge processing and acquisition (e.g., Larsen-Freeman and Long, 1991; chapters 3–4; Cook, 1993; R. Ellis, 1994, chapters 2–5; Sharwood Smith, 1994; Towell and Hawkins, 1994; Gregg, 1996; van Patten, 1996; Klein and Perdue, 1997; Pienemann, 1998a; 1998b; Carroll, 1999; 2000; Harrington, 2001). Thus, what almost all SLA theories, past and present, have in common, is a symbolist approach to second language (L2) development. The L2 learner is seen as progressing through a number of developmental stages or interlanguages, each represented by a grammar, consisting of symbols and rules, supplemented with a lexicon. Because of their linguistic roots, SLA theories tackle the issue of L2 development by distinguishing the 'what' from the 'how' of information processing, i.e., by distinguishing the representation of linguistic knowledge in terms of a property theory from the processing, acquisition and development of linguistic knowledge in terms of a transition theory. And they do so by giving priority to the former rather than the latter (Gregg, 1984; 1996), focusing on the description of interlanguage grammars (IL grammars). With IL grammars in focus, most SLA theories either neglect the mechanisms and processes that cause IL grammars to develop altogether, or they formulate such mechanisms in terms of linguistic (symbolic) constructs (for example, the well-known SVO Canonical Order Strategy proposed by Clahsen (1984), for the acquisition of German by speakers of Romance languages).

Language pedagogy has always tried to reconcile the what and the how of language learning, trying to foster language as knowledge as well as language as skill, albeit with different degrees of emphasis on either dimension depending on the views on knowledge and learning underlying the adopted teaching and learning method (e.g., Stern, 1992; Lightbown and Spada, 1999; Brown, 2001; Larsen-Freeman, 2001; Richards and Rodgers, 2001). The more recent literature focusing on form (Doughty and Williams, 1998) and tasks (Skehan, 1998; R. Ellis, 2000a; Robinson, 2001; Skehan and Foster, 2001) reflects and illustrates how difficult it is to integrate the knowledge and skill perspectives in L2 teaching and syllabus design harmoniously.

This article consists of three sections. In this section, the symbolist and connectionist accounts of the representation and processing/acquisition of knowledge are pitched against each other. Section II presents a speculative view on both the representation and processing/acquisition aspects of SLA in the form of nine claims and their clarifications. Section III discusses this view in the

light of the Noticing Hypothesis (Schmidt, 1994a; 1994b; 2001) and rounds the article off with some final remarks.

1 Overview of the theoretical landscape

This section lays out the theoretical landscape in which theories of SLA can be placed. This landscape sets the stage for a more in-depth treatment of key concepts below. Phenomena of language acquisition, language use and language deficiencies can be, and have been, described at three levels: the levels of behaviour, cognition and the brain (Simon, 1992; Green *et al.*, 1996: 5–7). Empirical studies collect either behavioural data (language production, language comprehension, judgements of grammaticality, lexical decisions, etc.) or they collect online or offline data concerning brain activity (Brown and Hagoort, 1999; Gazzaniga, 2000). The platform of cognition has become the privileged area of theory construction, especially since what is often referred to as the 'cognitive revolution', marked by the publication of Miller *et al.*'s seminal book 'Plans and the structure of behavior' (1960). The term 'cognition' refers to the representation of knowledge (information) in the mind/brain and to the processing and acquisition of information. Theories of language acquisition and use must answer three main questions. First, how can knowledge of language be represented (representation)? Secondly, how is language knowledge processed, e.g., during activities of listening, reading, speaking and writing (processing). And, thirdly, how is language knowledge brought into existence (acquisition/learning/appropriation)? It is acknowledged, however, that eventually cognition should be conceived as a much broader construct, encompassing not only information or knowledge, but also emotion and motivation (Pinker, 1997: 24–25; Schumann, 1998; Gray, 1999: 22; Mandler, 1999) and that cognition develops and exists in a social and cultural environment (Kramsch, 1998; Lantolf, 2000). This article is concerned mainly with representation and learning, and to a lesser extent with online processing.

Most linguistic theories aim to give a parsimonious account of the tacit linguistic knowledge of the ideal adult native speaker of a language (competence) by devising a formal architecture (grammar). Linguistic theories generally do not give an account of the day-to-day development of grammars during L1 acquisition, although they explicitly submit themselves to the requirement that a grammar must be learnable, i.e., can be induced from a finite set of well-formed sentences. Whereas the grammars of linguists usually only deal with the representation of knowledge,

psycholinguistic models usually focus on the processing or acquisition of knowledge. Currently, these models are often classified as either of the symbolist or of the connectionist (neural network) type, as described in the next section.

In contrast to accounts in the form of formal architectures, verbal, less formal, accounts of language learning can be given at the micro-level of learning mechanisms and at the macro-level of development. At the level of learning mechanisms or learning processes, two mechanisms are commonly distinguished: implicit and explicit learning (N. Ellis, 1994; Reber *et al.*, 1999). Implicit learning is a natural, nonconscious, and automatic process of gathering information, surface-level information as well as abstraction of underlying structure.[1] Explicit learning takes place consciously, either in the form of a search for underlying structure, or in the form of rule assimilation following explicit instruction.

Much of the literature on L1 development has centred around questions of modularity and nativism. Theories of L2 development have mainly been concerned with issues of L1 transfer, fossilization, acquisition orders, ultimate attainment and multi-competence (see, for example, Towell and Hawkins, 1994; Cook, 1997).

2 Symbolism and connectionism

Architectures that aim to account for the representation and processing/acquisition of knowledge can be categorized in two broad categories. In one type of architectures, knowledge is represented by means of symbols and operators or rules that specify the relationships between symbols. A symbol is a unit that can be given a context-independent interpretation (e.g., a letter, a phoneme). In another type of architecture, knowledge is represented not only by means of symbols but also in a distributed way, as a pattern of activation in a neural network containing hidden units. These hidden units contain, as it were, bits and pieces

[1] Implicit learning must be distinguished from implicit memory. The literature makes a task-related distinction between these two constructs. According to this distinction, implicit learning refers to acquisition of the regularities underlying events or objects. Examples are the learning of regularities in finite state grammars (e.g., the classical study of Reber, 1967), implicit sequence learning involving the reaction to event sequences following a certain non-obvious pattern (e.g., Nissen and Bullemer, 1987) and skill acquisition in solving complex problems resulting in automatic aggregation of event contingencies (e.g., the seminal study of Berry and Broadbent, 1984). The notion of implicit memory refers to the effects of past experiences with single events or objects, such as the priming effects of words encountered previously on reaction times in a lexical decision task (Jacoby, 1983; Schacter, 1987). Buchner and Wippich (1998) provide a review and discussion of the literatures on implicit learning and implicit memory; they point out that, unfortunately, the implicit memory literature says little about the representation and acquisition of implicit memory. The notion of implicit memory is left aside in this article.

of combinations of symbols; they are subsymbolic in the sense that they cannot be given a context-independent interpretation (e.g., the letter combination *st* anywhere in a word). The schools of thought associated to these two types of architectures are often called symbolism and connectionism respectively. There are two reasons, however, why one could argue that connectionism is not an entirely appropriate term for the class of Parallel Distributed Processing (PDP) models, which represent knowledge in a distributed way. The first reason is that connectionist models of the so-called localist type operate solely on symbols (they do not contain hidden units with distributed representations). Thus, strictly speaking, connectionism is too broad a term to refer only to PDP architectures (Grainger and Jacobs, 1998). The second reason is that many symbolic models could be said to be connectionist in that they too represent knowledge in the form of a network through which activation spreads and allow parallel information processing (Dijkstra and de Smedt, 1996). For example, Levelt's well-known speaking model (Levelt, 1989; Levelt *et al.*, 1999) may be said to fall into the category of symbolic architectures, but it uses procedures of parallel information processing (utterances are planned, formulated and pronounced incrementally) and activation spreading in the mental lexicon.

Symbolic models may aim to account for the representation of knowledge, the processing of knowledge, or both. Most linguists limit themselves to devising (formal) grammars for the representation of knowledge (called competence in generative linguistics). Such grammars belong to the class of declarative architectures (Daelemans and de Smedt, 1996). Procedural architectures (also called performance models) aim to model the manipulation of knowledge, thereby linking a start state and an end state of knowledge representation. Many psycholinguistic models of language comprehension and production are of the procedural type. Some symbolic architectures aim to model the process of skill acquisition (automatization); they contain a component of declarative and a component of procedural organization. Anderson's successive ACT architectures (Anderson and Lebiere, 1998) fall into this category.

In connectionist architectures, there is no principled distinction between representation, on the one hand, and processing or acquisition of information, on the other, since the static and dynamic aspects of cognition are tackled jointly. Learning takes place implicitly via an autonomous process of adjusting connection weights between nodes and adjustment of their activation levels. In connectionist models of the PDP type, knowledge is represented in

the activation pattern over many parallel-computing nodes in the hidden layer(s) of a neural network. Input nodes are connected to output nodes through a complex pattern of connections involving one or more layers of hidden units. The input and output nodes may consist of symbols, e.g., letters as input and words as output (in a model of the recognition of written words). Each node in the hidden layer(s) has an associated activation value that is computed from the values of its input. The interconnections have numerical weights to indicate the strength and polarity (positive or negative) of the relation between the connected nodes. Activation and association levels are expressed numerically; the values can increase and decrease to reflect changes in the system.

Symbolic and PDP models have their advantages and disadvantages. Symbolic systems achieve high levels of abstractions (e.g., the Merge procedure and the Determiner Phrase in generative grammar) and symbolic structures can account for the notion of productivity, that is, they represent an infinite number of actual structures through recursive rules (Fodor and Pylyshyn, 1988; Grainger and Jacobs, 1998). However, symbolic systems are complex and rigid, they are vulnerable when the properties of a single symbol change. Each exception to a rule requires additional rules and more processing (Daelemans and de Smedt, 1996: 43–44).

In PDP models, disturbances in the input and connections leads to a gradual, rather than an abrupt deterioration of performance, the so-called graceful degradation. Neural networks are eminently suited for finding solutions to problems with a large number of irregular and often competing or even conflicting constraints (Murre and Goebel, 1996: 60). On the down side, however, neural networks have, thus far, not proved to be very good at symbol manipulation (Pinker, 1997).

Most connectionist models of the 1980s linked input nodes directly with output nodes. For instance, Sokolik and Smith (1992) modelled the assignment of grammatical gender (masculine/feminine) of French nouns on the basis of 224 input nodes (26 letters × 8 letter positions). This model was too simplistic to be valid (as was pointed out by Carroll, 1995), notwithstanding its remarkable performance. Later connectionist models, of the so-called Recurrent Network type, contain (1) at least one level of hidden units, (2) a level of contextual units to account for memory of previous inputs and (3) an activation pattern known as backpropagation to allow for an interactive process of adjustment of activation weights. Connectionists such as Plunkett and his associates, although at first unwilling to accept a compromise with symbolists, now appear to allow some sort of symbolic knowledge

to be represented in their networks. In their 'Introduction to connectionist modeling of cognitive processes', McLeod *et al.* (1998: 276) state that networks with recurrent connections can form 'basins of attraction' so that inputs within a given range will eventually settle on an identical output:

> To the extent that attraction basins are insensitive to small variations in input, they could be considered to have a symbolic quality ... Perhaps the connectionist equivalent of a symbol is a stable point of attraction in a recurrent network. Rule-governed behavior might be the trajectory through a series of attractor basins which a network passes through in performing a task such as processing a sentence.

Thus, in some so-called hybrid models, the subsymbolic nodes are bound together so that they act as a symbol. In other hybrid models, the symbolic elements have activation levels associated with them, and productions can take actions by manipulating activation levels.[2] In a discussion of symbolic and connectionist models, Carpenter and Just (1999: 258) claim that 'the two architectures are completely compatible abstractions, which suggests that a wise scientific strategy is to figure out their interrelation, rather than to choose between them.' In a similar vein, Smolensky (1999) pleads for the integration of the two approaches with the help of some notions of Optimality Theory, namely parallel optimization and soft constraints, replacing the sequential rule application and hard constraints of generative linguistics. Such an integration is demonstrated by Sun *et al.* (2001) in their CLARION learning model, which interactively links a subsymbolic with a symbolic network, allowing for bottom-up and top-down learning to take place simultaneously. The model appears to be able to simulate human learning in a complex cognitive task (vessel navigation) in conditions that vary in the amount of top-down processing in combination with bottom-up learning.

Thus, although the jury is still out at present, there appears to be room for some optimism in that new developments in connectionism might soon make neural networks compatible with

[2] This is the case in 3CAPS, Just and Carpenter's 'capacity-constrained concurrent activation-based production system' (Just and Carpenter, 1992). The procedural knowledge in 3CAPS consists of a set of modules called productions, each of which is a condition–action contingency that specifies what symbolic manipulation should be made when a given pattern of information arises in working memory. Following the principle of immediacy, various levels of productions (e.g., from word encoding to text-level representation during reading) are cascaded and nested. 'At the lowest levels of reading, the 3CAPS reading model resembles a connectionist model of word recognition; however, this level is embedded within increasingly higher levels that represent syntactic, semantic, text-level, and schematic processes' (Carpenter and Just, 1999: 264).

symbolic systems in their capacity to model complex forms of knowledge and processing/learning.

With respect to nativism, there are differences between some scholars in the symbolist school and most scholars in the connectionist school. Some symbolists claim that linguistic knowledge is encapsulated in its own module, relatively independent from other forms of cognition, such as visual perception and general cognition (the modularity claim; Fodor, 1983; Carston, 1996). Moreover, some symbolists claim that some of this linguistic knowledge, in the form of abstract principles of Universal Grammar, is already in place when children are born (nativism). Chomsky is the scholar who most typically represents this kind of symbolism (Chomsky, 1986).

Connectionists usually do not commit themselves to nativism of a domain-specific type. In the connectionist view it is not necessary to postulate that children are endowed with language-specific knowledge at birth. For learning and induction to take place, it suffices to postulate that children are born with the non-domain-specific capability to perceive stimuli as being similar and store them as such in memory. That is, the brain of the newborn is wired in such a way as to be able to encode and store stimulus information in its most rudimentary form. Connectionism shares this rejection of domain-specific nativism with child development theories such as dynamic system theory (Thelen and Smith, 1994), constructivism (Piaget, 1955; Karmiloff-Smith, 1994) and, more recently, emergentism (Elman, 1999; MacWhinney, 1999).[3] According to these schools of thought, higher forms of cognition and functioning grow out of lower forms through the interaction of subsystems such as visual perception, body control and language (Elman *et al.*, 1996).

II A new, speculative view on cognitive aspects of SLA

The literature in various linguistic, psycholinguistic and neurolinguistic domains does not converge on an integrated, coherent view on L2 learning (and L1 learning). Here, an attempt is made to reconcile most aspects of the relevant literatures. (The following publications have had a substantial impact on this attempt: N. Ellis, 1994; 1998; 2001; to appear; Schmidt, 1994a; 1994b; 2001; Segalowitz, 2000a; 2000b.) The result is, it must be emphasized

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[3] Thelen and Smith (1994: 41–43) criticize connectionism for focusing on states rather than on changes in development. Emergentism (which includes connectionism), however, explicitly aims to account for change of states (development). Thus, in retrospect, Thelen and Smith's dynamic systems theory may not be at variance with connectionism (as part of emergentism), despite the authors' own verdict.

from the outset, a speculative conceptualization, which will remain sheer speculation until empirical support has been found. The two key dimensions in this conceptualization are representation and processing/acquisition. The notion of automatization is only briefly mentioned (see, however, Segalowitz and Hulstijn, in preparation). The conceptualization is formulated in terms of the following nine arguments or claims.

1 Representation of knowledge

The first claim is that, in principle, knowledge can be represented in hybrid architectures consisting of modules, some of which use a subsymbolic, distributed representation while other modules are of a symbolic kind. In distributed modules, concepts are represented as activation patterns over several network nodes simultaneously. Stable constellations may achieve the status of symbols (i.e., context-independent units), which may function in other, symbolic modules which model higher levels of cognition. Content words (permanent form–meaning pairs) are examples of symbol-like nodes, but grammatical constructions can also attain symbol status (see point 6 below). An additional claim is that some linguistic knowledge is encoded and stored in a distributed network form, some in the form of rules, and some in both forms, as is illustrated below.

2 High vs. low linguistic domains

Language phenomena can be mapped on a scale ranging from high to low. The highest phenomena reside in the areas of pragmatics and discourse. Examples are the conventions for structuring verbal information in oral and written discourse. Such conventions can best be expressed in terms of rules, using 'symbols' (i.e., verbal labels for concepts) such as *older*, *younger*, *male*, *female*, *superior*, *subordinate*, *formal*, *informal*, etc. An example of such a rule-like convention is: 'When you address an elderly woman whom you don't know, say *madam*' and 'When you write a formal letter to an organization but you don't know anyone there by name, begin your letter with *Dear Madam/Sir*.' Although many language users have an explicit, declarative knowledge of such conventions, I speculate that, in principle, it is possible to acquire the correct use of such expressions implicitly and encode and store the information in a distributed network form, without rules. Small children learn forms of addressing people in their social environment without being given, nor deliberately searching for, the rules with which the

regularities can be expressed. Their knowledge might be represented in an associative form, without rules, and – initially at least – perhaps even without higher-order concepts. In later stages of cognitive development, children may learn higher-order concepts such as *younger–older*, *formal–informal*, and begin to 'analyse' their hitherto implicit knowledge so that it becomes additionally represented in a more analysed, metalinguistic (and hence symbolic) form, as proposed by Bialystok and Bouchard Ryan (1985).

The lowest linguistic phenomena consist of the most elementary features of acoustic and visual signals. Human beings have no explicit knowledge of these features. Cognitive scientists have developed models (i.e., architectures of the symbolic or subsymbolic type, mentioned in Section I) to account for phenomena of acoustic and visual perception. As language users and learners we are not aware of these representations. Nor are we aware of the way in which information is processed within these systems. Neither can we manipulate our own hearing and reading behaviour at this most elementary level. Whereas we are capable of consciously controlling high-level knowledge, we are incapable of controlling knowledge at the lowest end of the continuum. Not even phoneticians and speech therapists are capable of doing so. Our brains cannot instruct our ears to disregard tones of a certain frequency, nor can they instruct the eyes not to process instances of words beginning with the letter B in running text during normal reading.

Between these two extremes of high and low linguistic knowledge there are intervening domains. All linguistic schools recognize, in one way or another, domains of phonetics, phonology, morphology, syntax, lexis, semantics and discourse, although the accounts of these domains and the definitions of their boundaries vary from one school to the other. Almost all linguistic theories so far have couched their accounts in the form of symbolic architectures. The number of alternative accounts, in terms of connectionist networks of the distributed kind, are growing, however, especially in the domains of phonology and morphology. It is an open question which type of model will turn out to be capable of giving the best account for which linguistic domain. My speculation is that symbolic representations will turn out to outperform subsymbolic representations in the highest domains, whereas subsymbolic representations will turn out to provide the best accounts in the lower domains.

3 Nativism

The earliest forms of language acquisition take place when children, in their first year of life, begin to perceive acoustic signals as somehow 'similar' and to categorize them as such. This means that, in terms of association networks, the earliest nodes are being built and their connection weights are being adjusted. In terms of neurophysiology, this means that certain designated areas of the brain (for most individuals various areas of the left hemisphere) become specialized in storing and processing phonological and prosodic information for receptive and productive purposes (Fabbro, 1999). This account hinges on the assumption – and this is my third claim – that infants are equipped with two gifts, themselves not the product of learning, namely the ability to perceive similarities in certain acoustic and visual stimuli, and the ability to store perceived similar stimuli in a manner that reflects these similarities (compare Aslin *et al.*, 1999). In cognitive architectures such capabilities are implemented by means of, for example, the number of input, hidden and output units, the initial connection weights, allowances for backpropagation, etc. Not much is known about what this form of nativism might mean in neurobiological terms. Note, however, that the fact that certain areas of the brain are likely to develop into designated, module-like specialists in processing particular kinds of linguistic information does not imply that some linguistic knowledge must already be present in the hard wiring of these areas at birth. However, this view does not rule out the possibility that some form of language-specific knowledge (e.g., equivalent to the principles of Chomsky's Universal Grammar) may emerge at a later stage of development.

With these gifts, of perceiving similarities of stimuli and storing encodings of similar stimuli, newborns are capable of learning in the implicit mode. Their learning is influenced by frequency effects and the power law of learning (N. Ellis, 2002). The postulation of these innate capabilities is necessary to allow humans to solve the existential problem of induction. Although connectionists have not been able to provide convincing evidence that all aspects of grammars can be acquired by mere exposure to language input and via 'implicit negative evidence', it is my speculation that cognitive scientists will provide such evidence in the not too distant future.[4]

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[4] See the debate between Marcus (1999) and Rohde and Plaut (1999b) on the question of whether induction of language knowledge is possible with 'implicit negative evidence' but without innate language-specific knowledge.

4 The special status of lexical units in language learning

With respect to the distinction between higher and lower domains of language knowledge, I would like to entertain the idea that sublexical units must be relegated to the lower end of the continuum, whereas units from the lexical level upwards can (but need not) assume the status of higher cognition. What gives the level of lexical units a special status is the fact that it is at this level that linguistic forms are matched with meanings.[5] This makes them more amenable to conscious, metalinguistic reflection than formal units at the sublexical and supralexical levels (such as phonemes and grammatical constructions respectively). Lexical units (free and bound morphemes), being rather stable form–meaning pairs, could be said to be relatively constant in their form–meaning unity, at least in comparison to units such as 'speech sound' at the sublexical level or 'verb phrase' at the supralexical level. The most characteristic feature of a lexical unit is that it consists of a permanent mapping of a fixed sequence of phonemes onto a (more or less) fixed meaning.[6] The fact that lexical units, and in particular content words, carry meaning makes them more susceptible to consciousness (i.e., to conscious reflection and control), than units below the lexical level. This is why lexical units can easily achieve the status of symbols. Of course, units at lower levels, such as phonemes, can also obtain symbolic quality, but lexical units are special because of their relative semantic permanence.

Lexical units have a pivotal function in both representation and learning. Because of their frequency and of their relative permanency, lexical units are identified automatically by skilled language users (Rayner and Pollatsek, 1989). Learning to recognize spoken and written words is a process that is subject to the power law of practice (N. Ellis, 2002), a prototypical example of 'repetition priming' (Gupta and Dell, 1999), and hence a form of implicit learning.

5 Explicit, metalinguistic knowledge

During the first four or five years of their lives, children acquire linguistic knowledge in an implicit way and store this implicit knowledge in various areas of the left hemisphere. In cognitive

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[5] Jackendoff (1999) attributes a crucial role to the lexicon as it forms the interface between the syntactic, phonological and semantic components of grammar.
[6] In the definition of Cruse (1986: 77) a lexical unit is 'the union of a lexical form and a single sense'. Examples of lexical units are: obey, disobey, kick, bucket, to kick the bucket. Levelt (1989: chapter 6) makes a distinction between a lexical item's lemma and form. The lemma comprises semantic and syntactic information.

architectures this implicit knowledge might be represented in the form of neural association networks of the distributed and localist kind. In societies where children go to school, children may form explicit, or 'analysed' linguistic knowledge. This is knowledge that can, in principle, be talked about. Early metalinguistic concepts are 'word', 'letter', 'sound', 'meaning', etc. In later years, the school curriculum may make students familiar with notions such as 'noun', 'verb', 'stem', 'ending', etc. These notions may serve as the tools with which prescriptive rules are taught in the mother-tongue and foreign-language curricula. The rules in most pedagogic grammars are limited to a rendition of what linguists call 'surface structure'. But their nature is not different from the rules to be found in linguistic treatises. They are made from the same 'stuff', namely rules and symbols. The notion 'rule' is itself a product of higher cognition. It is higher cognition of the symbolic and metacognitive kind that distinguishes humans from other living creatures (Deacon, 1997; Nelson, 1999). Thus, the conventional way to communicate about language systems is in terms of pedagogical or scientific grammars, in school and academia respectively. Metalinguistic knowledge is a kind of declarative knowledge (i.e., knowledge of facts and events that are recollected consciously). Declarative knowledge resides in particular areas of the brain (the medial temporal lobe, including the hippocampus), independent of the areas where implicit knowledge resides. Implicit knowledge is served by different and rather diffuse brain structures (Paradis, 1994; Reber, Allen and Reber, 1999; Squire and Knowlton, 2000; Ullman, 2001). This may be the reason why implicit memory is less vulnerable to neurological damage than explicit memory.

6 Implicit and explicit learning

We can now redefine the notions of implicit and explicit learning by characterizing them in terms of both the representation and processing of linguistic information. 'Implicit learning' is the construction of knowledge in the form of neural networks. At the lower levels of linguistic knowledge the nodes are of a subsymbolic nature; at higher levels, nodes may be conceived of as symbols (as in the hybrid architecture proposed by Carpenter and Just, 1999, mentioned in Section I, subsection 1). The strength of association between the network nodes changes in the beginning stages of learning with accumulating exposure, following a power law. At some point in time, connection weights in some parts of the network hardly change anymore. These network parts, or mini-networks, attain the status equivalent to 'symbols', i.e., relatively

context-independent units. These are the 'basins of attraction', referred to in the introduction, which have become insensitive to new input (McLeod *et al.*, 1998). Lexical units are the most obvious instances of such symbols. But grammatical construc-tions could perhaps attain symbol status too (e.g., constructions such as the intransitive, transitive, resultative, ditransitive and caused-motion constructions as defined by Goldberg, 1998; 1999).

Implicit learning is an autonomous process, taking place whenever information is processed receptively (through hearing and seeing), be it intentionally and deliberately or unintentionally and incidentally.[7] Implicit learning is not under conscious control. That is, once we have decided to listen, read, speak or write, we cannot choose not to encode and store information, or not to adjust the connection weights in our network. Implicit learning is unstoppable in the sense that it is not under conscious control and that its processing components cannot be verbalized.

If implicit learning is unstoppable, how can we account for the fact that L2 learning, despite massive exposure, training and motivation often does not lead to native-like performance, instead exhibiting persistent L1 interference or fossilization? In the words of Mehler and Christophe (2000: 905): 'Can we reconcile cortical plasticity with behavioral rigidity?' I acknowledge that I do not have a solution to this obvious anomaly. In some individuals, the mind-brain appears to have difficulty in adjusting connection weights and creating L2-appropriate input–output connections once it has settled on, and committed itself to, the properties of an L1 (Rohde and Plaut, 1999a). Why this is so for some and not for other individuals is, as yet, unknown.

'Explicit learning' is the construction of explicit, verbalizable, metalinguistic knowledge in the form of symbols (concepts) and rules, specifying relationships between concepts. Explicit learning is a conscious, deliberative process of concept formation and concept linking. This may either take place when learners are being taught concepts and rules by an instructor or textbook, or when they operate in a self-initiated searching mode, trying to develop concepts and rules themselves. Explicit learning, therefore, requires a certain cognitive development, and will generally not occur in early childhood. In most instructional settings around the world, explicit teaching and learning are the preferred modes of instruction and knowledge acquisition. This is true for many school subjects, including foreign-language curricula.

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[7] See Hulstijn (2001; to appear) for an in-depth treatment of the notions of incidental and intentional L2 learning.

7 Explicit L2 learning with concomitant implicit L2 learning

When we learn a foreign language with the rules of a pedagogic grammar, we construct explicit knowledge consisting of concepts and rules. We can try to apply these rules while speaking. This is extremely difficult because we can manipulate and control, 'online', only a very small amount of information in our working memory. To my knowledge, neuroscientists have not yet able to demonstrate, in precise neurophysiological terms, how the area of the brain where explicit knowledge resides (the medial temporal lobe and hippocampus) and the area which carries control (the frontal temporal lobe) could somehow collaboratively act as 'instructors' to other brain areas where implicit knowledge (skills, habits, reflexes) is created. In terms of cognitive architectures, proceduralization of explicit knowledge would entail that, somehow, the representation of declarative knowledge would transform or convert into implicit knowledge. Anderson's ACT architecture claims to be able to perform just that conversion (Anderson and Lebiere, 1998; Anderson, 2000). Note, however, that proceduralization, in Anderson's model, requires the processing of the required information over a great number of trials, during training. Thus, it may be the repeated processing of primary linguistic information that establishes implicit knowledge. The most likely conceptualization of proceduralization is not that explicit, metalinguistic knowledge actually transforms into implicit knowledge, but rather that a separate network is constructed of an implicit nature (Willingham and Goedert-Eschmann, 1999).

Since implicit learning takes place as an unstoppable information processing mechanism, it will automatically accompany explicit learning activities whenever L2 learners engage in practising the pronunciation of a particular sound, or producing a grammatical structure. By practising the brain constructs a knowledge base of an implicit type. We may be inclined to view L2 learning as taking place exclusively in a productive mode, but L2 learning is not an exclusive process of production; it includes reception.[8] Thus, L2 learners, intentionally operating in an explicit learning mode, have also been exposed to a greater or lesser extent to L2 input by hearing or reading what others (and even they themselves) say or write. The processes of hearing and reading, by their very nature, imply the construction and adjustment of knowledge representation in a network

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[8] Learning an L2 through speaking and writing, without any listening and reading, although logically conceivable, is not taken into consideration here.

form.[9] Thus, explicit L2 learning need not take place in the absence of implicit L2 learning.[10] Learners who have chosen to try to master an L2 with the help of grammar rules, and are thus engaged in processing primary linguistic information (during listening, reading, speaking and writing activities) cannot prevent a process of implicit learning taking place simultaneously.

Anderson's ACT theory of skill acquisition may not be at variance with the view just described. Proceduralization in Anderson's theory is commonly interpreted as necessarily requiring prior declarative knowledge that one is aware of and that one can verbalize. Anderson's declarative knowledge, however, need not be of the metacognitive type; some of its elements are of a subsymbolic nature of which people do not have conscious, verbalizable knowledge (Anderson and Lebiere, 1998: 11–12). Yet, declarative knowledge is defined as 'things we are aware we know and can usually describe to others' (Anderson and Lebiere, 1998: 5). It is unfortunate that Anderson, in his many publications spanning more than two decades, has unwittingly nourished confusion among educationalists who have interpreted Anderson to mean that all declarative knowledge can always be verbalized with rather sophisticated terminology (e.g., 'add -*s* to the stem of the verb when the subject is third person singular and the predicate is in the present tense').

Concerning the question of whether explicit and implicit L2 learning may complement each other or whether the one can do the job for the other, my definition of implicit and explicit learning leads me to conclude that L2 learners *do* have a free choice, but that is only the choice of whether or not to adopt an explicit learning mode. However, learners cannot freely choose to learn in an implicit mode simply because implicit learning takes place autonomously, beyond conscious control, whenever they engage in listening, reading, speaking or writing activities.

In terms of interface positions, my view can be categorized as a non-interface position, in that it rules out the possibility that

[9] Implicit learning through hearing is a more natural learning process than learning through reading, which requires, initially (i.e., during the acquisition of literacy skills) a stage of explicit learning, involving visual perception areas of the brain.

[10] The process of speech production entails a component of speech perception, in that speakers hear, and process, their own output (Levelt, 1989). Thus, even the L2 production process itself necessarily entails a form of input processing, and hence of implicit learning. However, if this were the only input learners would get, no substantial amounts of implicit L2 learning would take place.

explicit knowledge transforms into implicit knowledge.[11] A similar view has been expressed by Paradis (1994; 2000). R. Ellis, who previously inclined towards a weak interface position (R. Ellis, 1993) has changed to what could be called a non-interface position too (R. Ellis, 2000b). One of the most prominent defenders of the non-interface position is Krashen (1981; 1985). Note, however, that whereas Krashen (1982; 1985; 1999) is sceptical about the practical usefulness of explicit L2 knowledge, I consider explicit knowledge to be a worthwhile, sometimes indeed indispensable, form of knowledge to be used as a resource where and when implicit knowledge is not (yet) available.

Most contributions to the noninterface, weak interface and strong interface debate are couched in rather vague terms, not specified with reference to cognitive architectures or to brain areas.[12] The question then arises as to whether we are dealing with an empirical issue at all. If not, we may be wasting our time with a non-issue.

In behavioural terms, whereas it is possible to operationalize explicit knowledge as knowledge that can be verbalized with the use of labels for concepts (such as third person singular, verb stem, ending and /s/), there is no consensus on the operationalization of implicit knowledge. How should it then be possible to test the claim that practising explicit knowledge can lead to implicit knowledge? Perhaps dual-task methodology or the online measurement of event-related brain potentials (ERPs) will allow us to observe the involvement of implicit knowledge in the processing of linguistic information.

8 Motivations for adopting an explicit approach to L2 learning

Successful implicit L2 learning – resulting in accurate, fluid and fast performance – may take an extremely long time. It may take more time even, perhaps, than (implicit) L1 learning, as the brain is already committed to L1 and the L2 has to compete with the resources already taken by L1 (Rohde and Plaut, 1999a). Many L2 learners simply do not have the time to expose themselves long enough to L2 input to 'let implicit learning do the job'. Moreover, many L2 learners have developed, over the years of

[11] Note that I have changed my view substantially over the years. In Hulstijn (1990), for instance, I argued for a strong interface position, and in Hulstijn and De Graaff (1994: 101), I argued with De Graaff that it would be wise to adopt the interface position as a research-strategic framework in order to investigate under what conditions explicit instruction of grammar rules furthers L2 acquisition.

[12] Paradis (1994) forms an exception. He specifies implicit and explicit knowledge in terms of the brain areas concerned.

functioning in a literate society, information-gathering and learning strategies of a highly efficient type. (In a literate society, strategic, rule-like behaviour affords the individual with many daily advantages.) Perhaps, these individuals are, under the circumstances, best served by explicit learning (along with engagement in listening and reading activities promoting implicit learning) guided by the rules of thumb of pedagogical grammars. It would be advisable to make these facts known to L2 learners as part of an 'awareness' component in L2 instructional programmes. Learners may be told that, in a way, they 'fool themselves' by believing that they cannot learn a foreign language without the help of grammar rules, but that, at the same time, for many learners learning with grammar rules may still be the best choice to make. Thus, on the one hand, learners should know that it is essential to be exposed to large amounts of L2 input through listening and reading activities. But, given the limited opportunities for receiving extensive input in most L2 learning programmes, L2 learners should know that explicit knowledge may prove to be a helpful additional source of information (DeKeyser, 1998; 2000). Explicit knowledge is especially helpful in situations allowing careful monitoring of the information to be understood or produced, for example in situations of reading or writing without time pressure. Thus, within these limits, research into the effect of focus on form and feedback in an instructional context will continue to have a high educational value and priority.

9   *Automatization*

In the integrated view proposed here, performance fluency is the result of implicit learning, and automatization is a concomitant, incidental feature of implicit learning. Automatization follows the power law of learning both in what Gupta and Dell (1999) call 'repetition priming' and 'skill learning'. Repetition priming takes place when we process identical stimuli again and again (i.e., when we process the same word many times), whereas skill learning takes place when we process stimuli which (1) differ in some respect at the surface, but (2) share commonalities or regularities at an underlying level of structure.

Is it possible, or even necessary, to distinguish a separate notion of automatization in the case of explicit learning? In line with the argument propounded above (point 7), it is argued here that what may appear to be automatization of explicit, declarative knowledge through the formation of procedural rules and the formation of

motor programmes (Anderson's ACT theory), is, in fact, the building of a neural network *separately from*, and *in addition to*, the existing explicit, declarative, exclusively symbolic knowledge base, probably located in different brain areas. Thus, what may appear to be automatization of explicit knowledge is in fact automatization through implicit learning and neural network construction. In this view, therefore, there is no need to distinguish two types of automatization.

This claim may run counter to conventional views of skill learning. According to conventional wisdom, we may automatize factual rule knowledge by applying and practising the rules until the entire procedure can be executed without conscious control. According to the view proposed here, however, it is impossible to speak of the 'automatization *of* rules', as we do so often in colloquial speech. It may be possible to speed up the execution of algorithmic rules to a limited extent. But 'speeding up' is a quantitative change in the execution of a programme. It does not entail a qualitative change, the hallmark of true automatization. Mere 'speeding up' may thus be said to form 'false automatization'.[13]

In summary, according to the view propounded here, automatization is an incidental feature of implicit learning, subject to the power law and, hence, dependent on frequency of information processing. Its practical value is enormous as automatization of lower-order information processing leads to performance fluency, leaving learners' attentional resources to focus on cognitive fluency. Given the definitions of implicit and explicit learning provided under 6, however, the notion of automatization does not add much substance in terms of theoretical explanation.

III Discussion

In this section, some constructs which have been around in the SLA literature for a number of years are first examined in the light of the integrative account proposed in the previous section.

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[13] In order to empirically distinguish between qualitative and quantitative change, Segalowitz and Segalowitz (1993) used the coefficient of variability (CV) – the standard deviation of response time divided by the mean latency – an index widely used in cognitive psychological research. They applied the CV in the longitudinal measurement of L2 learners' word recognition performance. The results suggested that, initially, reaction times decreased while the CV remained unchanged – indicating speed up only – while later, with increasing practice, the CV decreased as well, indicating automatization.

1 Noticing

In the characterizations of implicit and explicit learning given here, the constructs of learning and knowledge are inseparable, but can still be distinguished. Schmidt (1994a), in an influential article in which he attempted to clarify a whole range of terminological issues, recommended clearly separating learning from knowledge, that is, separating processes from end-products (p. 20). That was a badly needed recommendation at the time. But in the light of the connectionist-inspired perspective taken here, implicit learning and knowledge need not – indeed cannot – be separated.

Some related constructs that Schmidt has brought to the fore in other publications (Schmidt, 1992, 1994a, 1994b, 2001), are 'awareness', 'consciousness', and 'noticing'. Obviously, these notions play an essential role in explicit learning; but can they play a role in implicit learning too? Implicit learning, as defined in this article, is the construction of neural networks of the distributed type (and, perhaps also, some modules of the symbolic type). That is, whereas the input and output nodes may consist of symbols, the network's knowledge is represented in subsymbolic, hidden units and in the pattern of activity in the network. Clearly, learners cannot be aware, notice or be conscious of these hidden units and these activation patterns, but learners might be aware, notice or be conscious of some input and output units. Thus, in principle, it is entirely conceivable that learners pay conscious attention to some sounds, words, word forms and words strings, together with their meanings (noticing), while simultaneously being incapable of being aware of how the neural correlates of these notions are neurally being linked (Schmidt, 2001; van Patten, 1996). The extent of the importance of noticing form–meaning relations remains to be established in empirical research.

2 Property vs. transition theory

The view on L2 learning expressed in this article takes into account both representation of knowledge and the acquisition of knowledge. According to Chomsky (1982), quoted by Gregg (1984: 95), it is 'suicidal' not to be concerned with representations. In Gregg's view, knowledge of language must be represented in the form linguists use to lay out linguistic regularities, that is, in a so-called 'property theory', with principles, rules, filters and similar tools. Language development, in this view, is seen as a trajectory through a series of interlanguage grammars. Each developmental stage is described in terms of a grammar of the rule type. In Gregg's

view, it is the task of another theory, the so-called 'transition theory', to account for the transition from one interlanguage grammar to another. This division of labour clearly emanates from the assumption that knowledge representation and knowledge acquisition are two entirely different phenomena. The advantage of the connectionist approach is that it aims to account for representation and acquisition in one and the same form. So far, connectionists have only been able to demonstrate that neural networks can learn what linguists regard as 'simple' or 'benign' linguistic facts, such as the past tense forms of regular and irregular verbs (Rumelhart and McClelland, 1986; Jensen and Ulbaek, 1994), grammatical gender of nouns (Sokolik and Smith, 1992), and case endings in German and Russian noun phrases (Kempe and MacWhinney, 1998). No demonstrations have been given of networks being able to learn subtle restrictions such as subjacency, binding principles and the like. Thus, while it is true that the jury is still out, I optimistically speculate that cognitive science will soon provide empirical support for the claim that even such much more subtle regularities can be learned by, and represented with, an associative network of some connectionist specification. It appears necessary, however, to allow networks to operate on symbol-like nodes, that is mini-networks of a stable nature that can function at higher levels of representation and learning. The higher these symbols are located in the network, the more likely it is that we can obtain a conscious awareness of their existence. The most obvious and privileged examples of such symbol-like nodes are lexical units because of the relative permanency in their form–meaning mapping. But other, more abstract, units may as well emerge as categories that are functional in learning grammatical regularities. In this respect one could think of argument-structure constructions such as the intransitive, transitive, resultative, ditransitive and caused-motion constructions as defined by Goldberg in her Construction Grammar (1998; 1999).

3 Further research

The view expressed in this article, it is reiterated here, is highly speculative. It can only be accepted when supported by empirical evidence. This evidence may take several forms. One branch of research to be furthered is neurolinguistic research (Paradis, 1994; Perani *et al.*, 1998; Brown and Hagoort, 1999; Fabbro, 1999; Weber-Fox and Neville, 1999; Gazzaniga, 2000; Green, 2001; Vaid, in press). Issues such as the distinction, and perhaps even the complete dissociation, between implicit and explicit learning might be

resolved with the aid of neuro-imaging research. The same holds for functional modularity in the representation and processing of linguistic information. The recent explosion of studies using PET and fMRI techniques suggests that the twenty-first century is going to be the century of the brain. Another branch that may support our view is connectionist modelling. It is urgent to find out whether connectionist networks of some architecture are able to learn the more subtle or 'difficult' phenomena of grammar, such as subjacency, binding principles and the like. Of particular interest to the field of SLA would be studies which aim to train a network to learn a component of one language first (the L1), and then train the network to learn a similar component in another language (the L2), which may or may not be related to the first one and, therefore, may or may not give rise to cross-language interference. Promising examples in this respect are Broeder and Plunkett (1994; 2000) and the studies by Kempe and MacWhinney (1998; 1999). A noteworthy feature of the Kempe and MacWhinney studies is that they exhibit a two-pronged approach. These researchers conducted connectionist simulations on their computers, while simultaneously conducting learning experiments with real L2 learners. The aim of this approach is, of course, to see whether and how well the results of the two methods dovetail. Laboratory experiments, under well-defined manipulation or control of relevant factors, are badly required. However, these experiments meet with many practical problems (Hulstijn, 1997; Norris and Ortega, 2000). Perhaps the main problem is that, for substantial implicit learning to take place, participants need to be 'bombarded' with perhaps many thousands of stimuli. Few people are willing to participate in large numbers of laboratory sessions in order to take in the required amounts of input.

4 Final remarks

We are still far away from a general SLA theory, notwithstanding brave attempts to bring the 'conditions for second language learning' into a single taxonomy (Spolsky, 1989). In the last chapter of their survey of SLA theories, Mitchell and Myles (1998: 191) raise the question of 'One theory or many?' They conclude:

> Different research groups are pursuing theoretical agendas which center on very different parts of the total language learning process; while many place the modeling of learning grammars at the heart of the enterprise, others focus on language processing, or on L2 interaction ... On the whole, grand synthesizing theories, which try to encompass all aspects of L2 learning in a single model, have not received general support.

There are a number of reasons why the view propounded in Section II above should not be mistaken as a general theory of SLA. First, it is only concerned with cognition, not with the equally important social aspects of L2 learning. Secondly, even within the realm of cognition it is limited to the representation and processing/acquisition of knowledge; it does not address other dimensions of cognition, such as emotion, personality and motivation. More important perhaps, the ideas expressed in this article are too general and lack sufficient detail to warrant the label 'theory'. However, what they purport to do is to stimulate integrative thinking in the SLA research community, in the tradition of Carroll's Induction Theory (1999, 2000), Pienemann's Processability Theory (1998a; 1998b), Towell and Hawkins's model of SLA (1994: chapter 14), and the work of all other researchers, conscious of the fact that SLA theories have to account for both representation and learning mechanisms. The present article attempts to show how symbolist and connectionist approaches to (second) language learning might be reconciled in future work. Linguists in the SLA field must accept that a theory of language, such as generative grammar (in any of its forms), albeit successful in explaining the commonalities and differences of human languages, cannot as such be considered the best theory of the representation of linguistic knowledge in the mind of the language learner and user. Cognitive scientists, on the other hand, must accept that the jury is still out on the question of whether connectionist networks are capable of capturing all kinds of linguistic knowledge and language use.

IV References

Anderson, J.R. 2000: *Learning and memory: an integrated approach*. Revised edition. New York: John Wiley.
Anderson, J.R. and **Lebiere, C.** 1998: *The atomic components of thought*.

Mahwah, NJ: Erlbaum.

Aslin, R.N., Saffran, J.R. and **Newport, E.L.** 1999: Statistical learning in linguistic and nonlinguistic domains. In MacWhinney, B., editor, *The emergence of language.* Mahwah, NJ: Erlbaum, 359–80.

Berry, D.C. and **Broadbent, D.E.** 1984: On the relationship between task performance and associated verbalizable knowledge. *The Quarterly Journal of Experimental Psychology* 36A, 209–31.

Bialystok, E. and **Bouchard Ryan, E.** 1985: A metacognitive framework for the development of first and second language skills. In Forrest-Pressley, D.L., MacKinnon, G.E. and Waller, T.G., editors, *Metacognition, cognition, and human performance*, Volume 1. New York: Academic Press, 207–52.

Broeder, P. and **Plunkett, K.** 1994: Connectionism and second language acquisition. In Ellis, N., editor, *Implicit and explicit learning of languages.* London: Academic Press, 421–53.

—— editors, 2000: *Models of language acquisition.* Cambridge: Cambridge University Press.

Brown, C.M. and **Hagoort, P.,** editors, 1999: *The neurocognition of language.* Oxford: Oxford University Press.

Brown, H.D. 2001: *Teaching by principles: an interactive approach to language pedagogy*. Revised edition. London: Longman.

Buchner, A. and **Wippich, W.** 1998: Differences and commonalities between implicit learning and implicit memory. In Stadler, M.A. and Frensch, P.A., editors, *Handbook of implicit learning.* Thousand Oaks, CA: Sage, 3–46.

Carpenter, P.A. and **Just, M.A.** 1999: Computational modeling of high-level cognition versus hypothesis testing. In Sternberg, R.J., editor, *The nature of cognition.* Cambridge, MA: MIT Press, 245–93.

Carroll, S.E. 1995: The hidden dangers of computer modeling: remarks on Sokolik and Smith's connectionist learning model of French gender. *Second Language Research* 11, 193–205.

—— 1999: Putting 'input' in its proper place. *Second Language Research* 15, 337–88.

—— 2000: *Input and evidence: the raw material of second language acquisition*. Amsterdam: Benjamins.

Carston, R. 1996: The architecture of the mind: modularity and modularization. In Green, D. *et al. Cognitive science: an introduction.* Cambridge, MA: Blackwell, 53–83.

Chomsky, N. 1982: *Noam Chomsky on the generative enterprise.* Dordrecht: Foris.

—— 1986: *Knowledge of language: its nature, origin and use*. New York: Praeger.

Clahsen, H. 1984: The acquisition of German word order: a test case for cognitive approaches to L2 development. In Andersen, R., editor, *Second languages: a cross-linguistic perspective.* Rowley, MA: Newbury House, 219–42.

Cook, V. 1993: *Linguistics and second language acquisition.* London: Macmillan.

—— 1997: The consequences of bilingualism for cognitive processing. In De Groot, A.M.B. and Kroll, J.F., editors, *Tutorials in bilingualism*. Mahwah, NJ: Erlbaum, 279–300.

Cruse, D.A. 1986: *Lexical semantics*. Cambridge: Cambridge University Press.

Daelemans, W. and **de Smedt, K.** 1996: Computational modelling in artificial intelligence. In Dijkstra, T. and de Smedt, K., editors, *Computational psycholinguistics*. London: Taylor and Francis, 24–48.

Deacon, T.W. 1997: *The symbolic species: the co-evolution of language and the brain*. New York: Norton.

DeKeyser, R.M. 1998: Beyond focus on form: cognitive perspectives on learning and practising second language grammar. In Doughty, C. and Williams, J., editors, *Focus on form in classroom second language acquisition*. New York: Cambridge University Press, 42–63.

—— 2000: The robustness of critical period effects in second language acquisition. *Studies in Second Language Acquisition* 22, 499–533.

Dijkstra, T. and **de Smedt, K.** 1996: Computer models in psycholinguistics: an introduction. In Dijkstra, T. and de Smedt, editors, *Computational psycholinguistics*. London: Taylor and Francis, 3–23.

Doughty, C. and **Williams, J.,** editors, 1998: *Focus on form in classroom second language acquisition*. Cambridge: Cambridge University Press.

Ellis, N. 1994: Implicit and explicit language learning: an overview. In Ellis, N.C., editor, *Implicit and explicit learning of languages*. London: Academic Press, 1–32.

—— 1998: Emergentism, connectionism and language learning. *Language Learning* 48, 631–64.

—— 2001: Memory for language. In Robinson, P., editor, *Cognition and second language instruction*. Cambridge: Cambridge University Press, 33–68.

—— to appear: Connectionist learning, chunking, and construction grammar: the emergence of second language structure. In Doughty, C. and Long, M.H., editors, *Handbook of second language acquisition*. Oxford: Blackwell.

—— 2002: Frequency effects in language processing: a review with implications for theories of implicit and explicit language acquisition. *Studies in Second Language Acquisition* 24, 143–88.

Ellis, R. 1993: The structural syllabus and second language acquisition. *TESOL Quarterly* 27, 91–113.

—— 1994: *The study of second language acquisition*. Oxford: Oxford University Press.

—— 2000a: Task-based research and language pedagogy. *Language Teaching Research* 4, 193–220.

—— 2000b: The representation and measurement of L2 explicit knowledge. Paper read at the conference on 'Language in the mind', held at the National University of Singapore, 4–6 September 2000.

Elman, J.L. 1999: The emergence of language: a conspiracy theory. In

MacWhinney, B., editor, *The emergence of language*. Mahwah, NJ: Erlbaum, 1–28.

Elman, J.L., Bates, E.A., Johnson, M.H., Karmiloff-Smith, A., Parisi, D. and **Plunkett, K.** 1996: *Rethinking innateness: a connectionist perspective on development*. Cambridge, MA: MIT Press.

Fabbro, F. 1999: *The neurolinguistics of bilingualism: an introduction*. Hove: Psychology Press.

Fodor, J.A. 1983: *The modularity of mind*. Cambridge, MA: MIT Press.

Fodor, J.A. and **Pylyshyn, Z.W.** 1988: Connectionism and cognitive architecture: a critical analysis. *Cognition* 28, 3–71.

Gazzaniga, M., editor, 2000: *The new cognitive neurosciences*. Cambridge, MA: MIT Press.

Goldberg, A.E. 1998: Patterns of experience in patterns of language. In Tomasello, M., editor, *The new psychology of language*. Mahwah, NJ: Erlbaum, 203–20.

—— 1999: The emergence of the semantics of argument structure constructions. In MacWhinney, B., editor, *The emergence of language*. Mahwah, NJ: Erlbaum, 197–212.

Gray, P. 1999: *Psychology*. Third edition. New York: Worth.

Grainger, J. and **Jacobs, A.M.** 1998: On localist connectionism and psychological science. In Grainger, J. and Jacobs, A.M., editors, *Localist connectionist approaches to human cognition*. Mahwah, NJ: Erlbaum, 1–38.

Green, D., editor, 2001: The cognitive neuroscience of bilingualism. Special issue of *Bilingualism: Language and Cognition*.

Green, D. *et al.* 1996: *Cognitive science: an introduction*. Cambridge, MA: Blackwell.

Gregg, K.R. 1984: Krashen's Monitor and Occam's Razor. *Applied Linguistics* 5, 79–100.

—— 1996: The logical and developmental problems of second language acquisition. In Ritchie, W.C. and Bhatia, T.K., editors, *Handbook of second language acquisition*. San Diego, CA: Academic Press, 49–81.

Gupta, P. and **Dell, G.S.** 1999: The emergence of language from serial order and procedural memory. In MacWhinney, B., editor, *The emergence of language*. Mahwah, NJ: Erlbaum, 447–81.

Harrington, M. 2001: L2 sentence processing. In Robinson, P., editor, *Cognition and second language instruction*. Cambridge: Cambridge University Press, 91–124.

Hulstijn, J.H. 1990: A comparison between the information-processing and the analysis/control approaches to language learning. *Applied Linguistics* 11, 30–45.

—— 1997: Second-language acquisition research in the laboratory: possibilities and limitations. *Studies in Second Language Acquisition* 19, 131–43.

—— 2001: Intentional and incidental second language vocabulary learning: a reappraisal of elaboration, rehearsal and automaticity. In Robinson, P., editor, *Cognition and second language instruction*. Cambridge: Cambridge University Press, 258–86.

—— to appear: Incidental and intentional learning. In Doughty, C. and Long, M.H., editors, *Handbook of Second Language Acquisition*. Oxford: Blackwell

Hulstijn, J.H. and **De Graaff, R.** 1994: Under what conditions does explicit knowledge of a second language facilitate the acquisition of implicit knowledge? A research proposal. *AILA Review* 11, 97–112.

Jackendoff, R. 1999: The representational structures of the language faculty and their interactions. In Brown, C.M. and Hagoort, P., editors, *The neurocognition of language*. Oxford: Oxford University Press, 37–79.

Jacoby, L.L. 1983: Remembering the data: analysing interactive processes of reading. *Journal of Verbal Learning and Verbal Behavior* 22, 485–508.

Jensen, K.A. and **Ulbaek, I.** 1994: The learning of the past tense of Danish verbs: language learning in neural networks. *Applied Linguistics* 15, 15–35.

Just, M.A. and **Carpenter, P.A.** 1992: A capacity theory of comprehension: individual differences in working memory. *Psychological Review* 99, 122–49.

Karmiloff-Smith, A. 1994: Precis of beyond modularity: a developmental perspective on cognitive science. *Behavioral and Brain Sciences* 17, 693–706.

Kempe, V. and **MacWhinney, B.** 1998: The acquisition of case marking by adult learners of Russian and German. *Studies in Second Language Acquisition* 20, 543–87.

—— 1999: Processing of morphological and semantic cues in Russian and German. *Language and Cognitive Processes* 14, 129–71.

Klein, W. and **Perdue, C.** 1997: The basic variety or: Couldn't natural languages be much simpler? *Second Language Research* 13, 301–48.

Kramsch, C. 1998: *Language and culture*. Oxford: Oxford University Press.

Krashen, S.D. 1981: *Second language acquisition and second language learning*. Oxford: Pergamon.

—— 1982: *Principles and practice in second language acquisition*. New York: Pergamon.

—— 1985: *The input hypothesis*. Beverly Hills, CA: Laredo.

—— 1999: Seeking a role for grammar: a review of some recent studies. *Foreign Language Annals* 32, 244–57.

Lantolf, J., editor, 2000: *Socio-cultural theory and second language learning*. Oxford: Oxford University Press.

Larsen-Freeman, D. 2001: *Techniques and principles in language teaching*. Revised edition. New York: Oxford University Press.

Larsen-Freeman, D. and **Long, M.H.** 1991: *An introduction to second language acquisition research*. London: Longman.

Levelt, W.J.M. 1989: *Speaking: from intention to articulation*. Cambridge, MA: MIT Press.

Levelt, W.J.M., Roelofs, A. and **Meyer, A.S.** 1999: A theory of lexical access in speech production. *Behavioral and Brain Sciences* 22, 1–75.

Lightbown, P.M. and **Spada, N.** 1999: *How languages are learned*. Revised edition. New York: Oxford University Press.

MacWhinney, B., editor, 1999: *The emergence of language*. Mahwah, NJ: Erlbaum.

Mandler, G. 1999: Emotion. In Bly, B.M. and Rummelhart, D.E., editors, *Cognitive science*. San Diego, CA: Academic Press, 367–84.

Marcus, G.F. 1999: Language acquisition in the absence of explicit negative evidence: can simple recurrent networks obviate the need for domain-specific learning devices? *Cognition* 73, 293–96.

McLeod, P., Plunkett, K. and **Rolls, E.T.** 1998: *Introduction to connectionist modeling of cognitive processes*. Oxford, UK: Oxford University Press.

Mehler, J. and **Christophe, A.** 2000: Acquisition of languages: infant and adult data. In Gazzaniga, M.S., editor, *The new cognitive neurosciences*. Cambridge, MA: MIT Press, 897–908.

Miller, G.A. and **Chomsky, N.** 1963: Finitary models of language users. In Luce, D.R., Bush, R.R. and Galanter, E., editors, *Handbook of mathematical psychology*, Vol. 2. New York: Wiley, 419–92.

Miller, G.A., Galanter, E. and **Pribram, K.H.** 1960: *Plans and the structure of behavior*. New York: Holt Rinehart and Winston.

Mitchell, R. and **Myles, F.** 1998: *Second language learning theories*. London: Arnold.

Murre, J.M.M. and **Goebel, R.** 1996: Connectionist modelling. In Dijkstra, T. and de Smedt, K., editors, *Computational psycholinguistics*. London: Taylor and Francis, 49–81.

Nelson, T.O. 1999: Cognition versus metacognition. In Sternberg, R.J., editor, *The nature of cognition*. Cambridge, MA: MIT Press, 625–41.

Nissen, M.J. and **Bullemer, P.** 1987: Attentional requirements of learning from performance measures. *Cognitive Psychology* 19, 1–23.

Norris, J.M. and **Ortega, L.** 2000: Effectiveness of L2 instruction: a research synthesis and quantitative meta-analysis. *Language Learning* 50, 417–528.

Paradis, M. 1994: Neurolinguistic aspects of implicit and explicit memory: implications for bilingualism and SLA. In Ellis, N., editor, *Implicit and explicit learning of languages*. London: Academic Press, 393–419.

—— 2000: Awareness of observable input and output – not of linguistic competence. Paper read at the International Symposium on Language Awareness. University of Odense, Denmark, 28 April 2000.

Perani, D., Paulesu, E., Galles, N.S., Dupoux, E., Dehaene, S., Bettinardi, V., Cappa, S.F., Fazio, F. and **Mehler, J.** 1998: The bilingual brain: proficiency and age of acquisition of the second language. *Brain* 121, 1841–52.

Piaget, J. 1955: *The child's construction of reality*. London: Routledge and Keagan Paul.

Pienemann, M. 1998a: Developmental dynamics in L1 and L2 acquisition: processability theory and generative entrenchment. *Bilingualism: Language and Cognition* 1, 1–20.

—— 1998b: *Language processing and second language development: processability theory*. Amsterdam: John Benjamins.

Pinker, S. 1997: *How the mind works*. New York: Norton.

Rayner, K. and **Pollatsek, A.** 1989: *The psychology of reading*. Englewood Cliffs, NJ: Prentice Hall.

Reber, A.A. 1967: Implicit learning of an artificial grammar. *Journal of Verbal Learning and Verbal Behavior* 6, 855–63.

Reber, A.S., Allen, R. and **Reber, P.J.** 1999: Implicit versus explicit learning. In Sternberg, R.J., editor, *The nature of cognition*. Cambridge, MA: MIT Press, 475–513.

Richards, J.C. and **Rodgers, T.S.** 2001: *Approaches and methods in language teaching*. Revised edition. Cambridge: Cambridge University Press.

Robinson, P. 2001: Task complexity, cognition and second language syllabus design: a triadic framework for examining task influences on SLA. In Robinson, P., editor, *Cognition and second language instruction*. Cambridge University Press, 287–318.

Rohde, D.L.T. and **Plaut, D.C.** 1999a: Language acquisition in the absence of explicit negative evidence: how important is starting small? *Cognition* 72, 67–109.

—— 1999b: Simple recurrent networks can distinguish non-occurring from ungrammatical sentences given appropriate task structure: reply to Marcus. *Cognition* 73, 297–300.

Rumelhart, D. and **McClelland, J.** 1986: On learning the past tense of English verbs. In Rumelhart, D.E. and McClelland, J.L., editors, *Parallel distributed processing: explorations in the microstructure of cognition*, Volume 2: *Psychological and biological models*. Cambridge, MA: MIT Press, 272–326.

Schacter, D.L. 1987: Implicit memory: history and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 13, 501–18.

Schmidt, R. 1992: Psychological mechanisms underlying second language fluency. *Studies in Second Language Acquisition* 14, 357–385.

—— 1994a: Deconstructing consciousness in search of useful definitions for applied linguistics. *AILA Review* 11, 11–26.

—— 1994b: Implicit learning and the cognitive unconscious: of artificial grammars and SLA. In Ellis, N.C., editor, *Implicit and explicit learning of languages*. London: Academic Press, 165–210.

—— 2001: Attention. In Robinson, P., editor, *Cognition and second language instruction*. Cambridge: Cambridge University Press, 3–32.

Schumann, J.H. 1998: The neurobiology of affect in language. *Language Learning* 48, Supplement 1.

Segalowitz, N. 2000a: Automaticity and attentional skill in fluent performance. In Riggenbach, H., editor, *Perspectives on fluency*. Ann Arbor, MI: University of Michigan Press, 200–19.

—— 2000b: On the bridge between psychology and linguistics. Plenary article presented at the 2000 Annual Conference of the American Association for Applied Linguistics, Vancouver, March 11–14, 2000.

Segalowitz, N. and Hulstijn, J. (in press): Automaticity in second language learning. In J.F. Kroll and De Groot, A.M.B, editors, *Handbook of bilingualism: psycholinguistic approaches*. Oxford: Oxford University Press.

Segalowitz, N.S. and **Segalowitz, S.J.** 1993: Skilled performance, practice, and the differentiation of speed-up from automatization effects: evidence from second language word recognition. *Applied Psycholinguistics* 14, 369–85.

Sharwood Smith, M. 1994: *Second language learning: theoretical foundations*. London: Longman.

Simon, H.A. 1992: What is an 'explanation' of behavior? *Psychological Science* 3, 150–61.

Skehan, P. 1998: *A cognitive approach to language learning*. Oxford: Oxford University Press.

Skehan, P. and **Foster, P.** 2001: Cognition and tasks. In Robinson, P., editor, *Cognition and second language instruction*. Cambridge University Press, 183–205.

Smolensky, P. 1999: Grammar-based connectionist approaches to language. *Cognitive Science* 23, 589–613.

Sokolik, M.E. and **Smith, M.E.** 1992: Assignment of gender to French nouns in primary and secondary language: a connectionist model. *Second Language Research* 8, 39–58.

Spolsky, B. 1989: *Conditions for second language learning*. Oxford: Oxford University Press.

Squire, L.R. and **Knowlton, B.J.** 2000: The medial temporal lobe, the hippocampus, and the memory systems of the brain. In Gazzaniga, M.S., editor, *The new cognitive neurosciences*. Cambridge, MA: MIT Press, 765–79.

Stern, H.H. 1992: *Issues and options in language teaching*. Book posthumously edited by Allen, P. and Harley, B. Oxford: Oxford University Press.

Sun, R., Merrill, E. and **Peterson, T.** 2001: From implicit skills to explicit knowledge: a bottom-up model of skill learning. *Cognitive Science* 25, 203–44.

Thelen, E. and **Smith L.B.** 1994: *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.

Towell, R. and **Hawkins, R.** 1994: *Approaches to second language acquisition*. Clevedon: Multilingual Matters.

Ullman, M.T. 2001: The neural basis of lexicon and grammar in first and second language: the declarative/procedural model. *Bilingualism: Language and Cognition* 4, 105–22.

Vaid, J. in press: Bilingualism. In Ramachandran, V.S., editor, *Encyclopedia of the human brain*. San Diego, CA: Academic Press.

van Patten, B. 1996: *Input processing and grammar instruction*. Norwood, NJ: Ablex.

Weber-Fox, C.M. and **Neville, H.J.** 1999: Functional neural subsystems are differentially affected by delays in second language immersion: ERP and behavioral evidence in bilinguals. In Birdsong, D., editor,

Second language acquisition and the critical period hypothesis. Mahwah, NJ: Erlbaum, 23–38.

Willingham, D.B., and **Goedert-Eschmann, K.** 1999: The relation between implicit and explicit learning: evidence for parallel development. *Psychological Science* 10, 531–34.