Investigating the contribution of procedural and declarative memory to the acquisition of past tense morphology: Evidence from Finnish

Evan Kidd & Minna Kirjavainen

To cite this article: Evan Kidd & Minna Kirjavainen (2011) Investigating the contribution of procedural and declarative memory to the acquisition of past tense morphology: Evidence from Finnish, *Language and Cognitive Processes*, 26:4-6, 794-829, DOI: 10.1080/01690965.2010.493735

To link to this article: <http://dx.doi.org/10.1080/01690965.2010.493735>

Published online: 27 Oct 2010.

Submit your article to this journal [↗](#)

Article views: 514

View related articles [↗](#)

Citing articles: 7 View citing articles [↗](#)

Investigating the contribution of procedural and declarative memory to the acquisition of past tense morphology: Evidence from Finnish

Evan Kidd^{1,2} and Minna Kirjavainen¹

¹*School of Psychological Sciences, The University of Manchester, Manchester, UK,* ²*School of Psychological Sciences, La Trobe University, Bundoora, Melbourne, Victoria, Australia*

The present paper reports on a study that investigated the role of procedural and declarative memory in the acquisition of Finnish past tense morphology. Two competing models were tested. Ullman's (2004) declarative/procedural model predicts that procedural memory supports the acquisition of regular morphology, whereas declarative memory supports the acquisition of irregular morphology. In contrast, single-route approaches predict that declarative memory should support lexical learning, which in turn should predict morphological acquisition. One-hundred and twenty-four ($N = 124$) monolingual Finnish-speaking children aged 4;0–6;7 completed tests of procedural and declarative memory, tests of vocabulary knowledge and nonverbal ability, and a test of past tense knowledge. The results best supported the single-route approach, suggesting that this account best extends to languages that possess greater morphological complexity than English.

Keywords: Past tense morphology; Language acquisition; Finnish; Memory.

Correspondence should be addressed to Evan Kidd, School of Psychological Sciences, Faculty of Science, Technology and Engineering, La Trobe University, Bundoora 3086, Vic., Australia. E-mail: e.kidd@latrobe.edu.au

This research was supported by an Economic and Social Research Council grant to Evan Kidd (RES-000-22-2640). Preparation of the manuscript was supported by a Charles La Trobe Research Fellowship, also awarded to Kidd. We would like to thank Alexandre Nikolaev for his help with item selection, Jarrad Lum for his role in developing the tests, Jukka Hyöñä and two anonymous reviewers for helpful comments, and all of the children and kindergartens that took part. Order of authorship is arbitrary.

© 2010 Psychology Press, an imprint of the Taylor & Francis Group, an Informa business
<http://www.psypress.com/lcp> DOI: 10.1080/01690965.2010.493735

The acquisition and processing of past tense morphology have received a large amount of attention in the psycholinguistic literature, due to its use as a test case for one of the more controversial debates in cognitive science (e.g., McClelland & Patterson, 2002; Pinker & Ullman, 2002). On the one hand, the *dual-route* model argues that there are two distinct processes involved in the formation of the past tense. A symbolic, rule-based route is argued to be involved in the formation of regular past forms (e.g., *walk* → *walked*) via the application of formal symbolic rule (i.e., “add/-ed/ to the verb stem”). The past forms of irregular verbs are argued to be learnt associatively (e.g., *go* → *went*, *sing* → *sang*). On the other hand, *single-route* approaches argue that all past forms are processed via the same associative mechanism, and that analogies are made over stored forms (both words and morphemes) to create systematicity within the system.

Research on past tense formation spans the full complement of sub-disciplines in psycholinguistics, including acquisition, computational modeling, adult processing, and neurolinguistics. Research that has reported on studies conducted with human participants has presented arguments for either the dual or single-route approaches that are based on studies that report differences across linguistic variables (e.g., Berko, 1958; Bybee & Slobin, 1982; Clahsen, 1999; Marchman, 1997; Marchman, Wulfeck, & Ellis Weismer, 1999; Marcus et al., 1992; Matthews & Theakston, 2006; Prasada & Pinker, 1993, *inter alios*). In the current paper we take a different tact. We report on a large-scale individual differences study conducted with Finnish-speaking children aged 4;0–6;7 years. The children were tested on a battery of linguistic and nonlinguistic tasks that were chosen to test the specific developmental predictions of the single and dual-route approaches to past tense formation. In particular, we included a number of memory tasks that enabled us to test predictions derived from a recent proposal regarding the memory systems underlying past tense acquisition and processing (Ullman, 2001, 2004). Our results show greatest support for the single-route approach. In particular, the results show that children’s ability to form correct past forms is best predicted by a model where declarative memory predicts vocabulary acquisition, which in turn predicts knowledge of the past tense. We next outline the claims and specific predictions of the dual and single-route accounts, with special reference to acquisition.

THE DECLARATIVE/PROCEDURAL (DP) MODEL OF LANGUAGE

Ullman (2001, 2004) proposed the DP model of language, which is a neuropsychological analogue of the dual-route approach to language. According to the theory, the two memory systems support different aspects

of language. Procedural memory is argued to be responsible for the rule-based computation of regular verbs, and declarative memory for the storage of irregular past forms. Procedural memory system is responsible for the learning and control of complex skills that are not necessarily available to conscious reflection, such as playing the piano, swimming, and driving a car. The system is composed of various interconnected brain structures, the most important of which appear to be the frontal/basal-ganglia circuits (for a review see Ullman & Pierpont, 2005). The DP model therefore predicts that in acquisition the procedural memory system seizes upon the so-called rule-based aspects of language, such as regular morphological processes.

The declarative memory system is traditionally divided into “semantic” memory, which stores factual knowledge, and “episodic” memory, which stores memory for events. Semantic memory is the repository of lexical facts, including word meanings and other arbitrary linguistic information that are not predictable from hypothesised grammatical rules, such as verb argument structure information, idiomatic expressions, and high-frequency frozen or semi-productive constructions. Whereas procedural memory analyses complex patterns over numerous exposures, declarative memory is responsible for making rapid associations between arbitrarily related information. For instance, it is argued to be responsible for the learning of new words, where an arbitrary phonological form must be associated with conceptual information (Eichenbaum & Cohen, 2001). With respect to acquisition, the DP model predicts that declarative memory supports the learning of those aspects of language that are not predictable from grammatical rules, such as irregular verbs.

The evidence supporting the DP model is equivocal, and in every case comes from English, a language with an impoverished system of verbal morphology compared to many of the world’s languages. For instance, Ullman et al. (1997) reported that people with Parkinson’s disease, who present with impairments to the procedural memory system, showed impaired performance on the production of novel “regular”-like past forms in comparison to irregulars. In contrast, patients with Alzheimer’s disease, who present with impairments to declarative memory, exhibited the opposite pattern. These data minimally show that it is possible to be selectively impaired at regular and irregular morphology; however, they are also explained by arguments that these disorders result in selectively worse deficits in either phonology (in the case of Parkinson’s) or semantics (in the case of Alzheimer’s). For instance, Joannise and Seidenberg (1999) trained a connectionist network to learn the past tense of English regular and irregular verbs. The network was then lesioned to diminish its capacity to process either (1) phonological or (2) semantic information. The network was then tested on Ullman et al.’s materials, and exhibited the same pattern of results as Ullman et al.’s Parkinson’s and Alzheimer’s patients. Namely, when phonological

processing was impaired the network exhibited greater diminished performance on novel “regular”-like words than on irregulars, and when semantic processing was impaired the network performed comparatively worse on irregulars, thus capturing the same double dissociation within a single process model. These computational data have been supported by behavioural experiments with both healthy and brain-damaged adults (Bird, Lambon-Ralph, Seidenberg, McClelland, & Patterson, 2003; Braber, Patterson, Ellis, & Lambon-Ralph, 2005; Woollams, Joanisse, & Patterson, 2009).

In the developmental language disorders literature, two studies have reported that children with Specific Language Impairment (SLI) perform worse on tests of procedural memory than regularly developing children (Lum, Gelec, & Conti-Ramsden, 2010a; Tomblin, Mainela-Arnold, & Zhang, 2007). Since children with SLI tend to have problems with regular morphology (among other things), this provides some support for the DP model. However, any claims of direct support need to be tempered by the fact that SLI children also perform significantly worse than matched peers on tests of declarative memory for verbal information (Lum et al., 2010a). Another prominent finding that has been argued to support the DP model is that some studies have found sex differences in processing of past tense forms in English in both child language learners and adults, which has been attributed to the fact that females are argued to have better declarative memories than males (e.g., Hartshorne & Ullman, 2006; Prado & Ullman, 2009). However, at least in the case of children, these results do not hold up to more careful empirical scrutiny (Kidd & Lum, 2008; see also Wallentin, 2009).

SINGLE-ROUTE MODEL

The single-route model argues that the acquisition mechanism makes no distinction between so-called regular and irregular verbs. Instead, all verbs are argued to be processed by an associative learning mechanism that is sensitive to the item-level features of verbs. Various incarnations of single-route models exist; for instance, connectionist approaches, which argue for sub-symbolic representation (e.g., Joanisse & Seidenberg, 1999; Plunkett & Marchman, 1991, 1993; Rumelhart & McClelland, 1986), and schema-based and analogical models, which argue that past forms are generated on the basis of either local abstractions made over similar items, or online analogies made over sets of verbs (e.g., Daelemans, 2002; Skousen, 1989, 2003; but see Albright & Hayes, 2003; for an enlightened discussion see Dąbrowska, 2008).

The commonality between all single-route approaches is that they are inherently *usage-based*; they identify a central role for experience, storage, and computation in language acquisition and representation. Unlike the dual-route approach, where linguistic generalisations are formal and maximally

general (e.g., in English there is one past tense rule despite there being three regular allomorphs), these approaches argue that generalisations are graded and dependent on the shared properties of individual lexical items stored in the lexicon. Children are argued to build up lexical networks of phonologically and semantically similar items that are then accessed when a past form of a verb is required. Morphological structure is conceived as an emergent property of the connections between items in the lexical network (e.g., Bybee, 1995).

The single-route approach therefore makes the explicit prediction that children's morphological knowledge should be closely and intimately related to their vocabulary knowledge in a nontrivial manner. This is because children can only begin to generalise over their input once they have a sufficiently large evidential base. There are several results in the acquisition that support this assertion. Marchman and Bates (1994) reported that children begin to make overgeneralisation errors once they have acquired a critical mass of verb tokens (see also Bates & Goodman, 1997). Marchman, Saccuman, and Wulfeck (2004) reported significant correlations between vocabulary size and correct performance on a production task designed to elicit the past tense in typically developing children, children with focal brain lesions, and children with SLI.

These results are not limited to English. Based on parental report data, Stolt, Haataja, Lapinleimu, and Lehtonen (2009) reported positive relationships between Finnish-speaking children's vocabulary and their grammatical knowledge. Similar results have been reported in Hebrew (Maital, Dromi, Sagi, & Bornstein, 2000), German (Szagun, Steinbrink, Franik, & Stumper, 2006), Icelandic (Thordardottir, Weismer, & Evans, 2002), Italian (Caselli, Casadio, & Bates, 1999), and English-Spanish bilinguals (Marchman, Martínez-Sussmann, & Dale, 2004). Finally, in an experimental setting, Nicoladis, Palmer, and Marentette (2007) showed that 4-year-old bilingual children, who receive less language-specific input than their monolingual peers, made more past tense errors than monolingual controls when re-telling a story, and that these errors reflected properties of the particular language they were speaking (more errors for regular verbs in French, more errors for irregular verbs in English).

In contrast to these data, proponents of the dual-route model do not identify a prominent role for language experience in the acquisition of regular morphology, beyond identifying the rule, which is argued to be induced early in development. For instance, Marcus et al. (1992, p. 133) noted that English-speaking children begin to make overgeneralisation errors when they have as few as 100 verbs in their productive vocabularies, leading them to suggest that "children do not need to process large amounts of input to seize upon the regular pattern". The dual-route approach therefore predicts that although there should be a positive association between vocabulary size and knowledge of irregular verbs, this should not be the

case for regular verbs, whereas the single-route approach predicts a significant relationship between vocabulary and morphology regardless of verb type.

A recent study by Lum and Kidd (2010) tested the predictions of the dual-route-inspired DP model and the single-route model. They reasoned that, since the single-route model argues for a prominent role for vocabulary acquisition in the development of morphological knowledge, and since vocabulary knowledge is essentially declarative knowledge, a single-route model that incorporates long-term memory processes would identify a prominent role for the declarative system. Specifically, they suggested that declarative memory abilities should predict vocabulary knowledge, which in turn should predict morphological knowledge. They tested 100 English-speaking children aged 4;8–6;9 on tests of declarative and procedural memory, tests of vocabulary and nonverbal ability, and a test of past tense production. The results best supported the single-route account, which predicted the children's performance on regular and irregular words equally well.

The current study aimed to extend the work of Lum and Kidd (2010) to a language that has a very different morphological system to English: Finnish. Below we provide an outline of the past tense in Finnish, and provide a justification for our choice to study this language.

FINNISH: AN OVERVIEW

In comparison to English, Finnish verbal morphology is very complex. There are 25 verb classes (Suomen Kielen Perussanakirja, 1994), into which verbs are categorised based on their morphophonology and the way they inflect. The stem/base form of the verb is always inflected; it cannot appear without a suffix as can English infinitival forms (e.g., *want*). Verbs are inflected for four forms of infinitive, two forms of participle, four forms of mood, present and past tense, active and passive, and six forms of person (first, second, third person singular, and plural). They also take clitic-like suffixes (e.g., *kO*, *pA*, *hAn*).¹ Affixes denoting these inflections/clitics are often stacked to the stem form of the verb. See example (1):

- (1) *pela|si|tte|ko* (*Did you play?*)
 play|past tense|1pl|interrogative clitic

The acquisition of verbal morphology in Finnish is therefore potentially more complex than in a language like English. Consider the following

¹ Capital letters denote vowel harmony.

comparison. In English each verb can appear in four different surface forms (e.g., *walk*, *walks*, *walking*, *walked*). Although estimates for Finnish vary, there are theoretically up to around 260 paradigmatic forms in the language (excluding auxiliary + V combinations and verbs with clitic-like suffixes; Hakulinen et al., 2005), but there may only be around 150 forms attested in any Finnish corpus.² Even if we take the lower bound of these estimates, it is clear from these numbers that the acquisition of Finnish verbal morphology presents a comparatively larger challenge to children than does English.

Since the verb must always be inflected in Finnish, children begin to acquire verbal morphology from the moment they begin producing verbs.³ For instance, Toivainen (1997) reported on a longitudinal study of 25 Finnish-speaking children, and showed that some verbal suffixes are meaningful to children as young as 1;4. Using parental report data, Stolt et al. (2009) showed that Finnish-speaking children aged 2;0 acquire verbs and verbal inflections in a linear fashion, such that they acquire verbal inflections as they acquire more verb tokens. With respect to the past tense, Toivainen showed that children generally begin to inflect verbs for the past tense between 1;9 and 2;2, and do so to denote high-frequency events and activities common to the average experience of infants (e.g., *men-i* → *went*, *itk-i* → *cried*). However, such early use should not be taken as evidence for early mastery. For instance, Niemi (2006) tested 13–14-year-old school children's knowledge of the past tense using novel verbs, and found individual error rates as high as 47%. Let us consider the Finnish past tense in more detail.

Finnish has two past tense allomorphs (*-si* and *-i*), which are applied to a majority of Finnish verbs based on the phonological form of the verb's stem/base form. However, the past tense suffixation can also affect the form of the base form. Both of these suffixes can be seen as being at least to some degree productively processed (with the majority of words with which they appear).

The past tense suffix *-si* is used with so-called “contracted verbs” that, when in the present indicative active forms, have a long single vowel sequence in the end of the word, as in (2), or a combination of vowels uA, eA, OA, and iA, as in (3)–(6). On the other hand, the *-i* suffix is, for instance, used with verbs in which the labiality of the vowel in the first syllable of the stem results in the present tense indicative active stem-final “A” being deleted when preceding the past tense suffix, as in (7) and (8), making the *-i* suffix processes less agglutinative (and more fusional) and hence less productive than the *-si* suffix processes.

² We thank an anonymous reviewer for pointing this last estimate out to us.

³ Note that this in no way means that a child who knows one verb and one inflection has productive knowledge of that inflection, since it is more likely that the children have acquired the complex form as a holistic form (Tomasello, 1992).

	Infinitive	Third present	Third past	Gloss
(2)	pela ta	pela a	pela si	to play
(3)	halu ta	halu aa	halu si	to want
(4)	nime tä	nime ää	nime si	to name
(5)	inho ta	inho aa	inho si	to despise
(6)	hävi tä	hävi ää	hävi si	to lose
(7)	muista a	muista a	muist I	to remember
(8)	näyttä ä	näyttä ä	näytt I	to show
(9)	pump a ta	Pump p a a	pump p a si	to pump
(10)	pelä tä	pelk ä ä	pelk ä si	to be scared of

More often than not, one of the past tense suffixes can be added to the stem without any change to the stem itself. However, there are verbs whose stems change as a result of suffixation. In many cases these changes do not qualitatively alter the stem but instead alter the length of a phoneme in the stem (i.e., consonant gradation; see example 9). About 30% of the contracted verbs show such quantitative changes (i.e., consonant gradation) between the A-infinitive and past tense forms (Hakulinen, et al., 2005). These types of changes can be seen as being productive changes (i.e., they can be viewed as being regular processes). However, other verbs exhibit qualitative changes to the stem as a result of the suffixation process, as in (10). Qualitative stem changes are nonproductive and can hence be seen as fully irregular past tense processes. These occur for both past tense morphemes.

Since both morphemes can enter into ostensibly “regular” and “irregular” processes, it is rather difficult to identify a default suffix in Finnish. Marcus, Brinkmann, Clahsen, Wiese, and Pinker (1995) provided a list of criteria for identifying a default. However, the criteria are of little help in Finnish (see Kirjavainen, Nikolaev, & Kidd, 2010), and nor have they proven to be useful in other highly inflected languages (e.g., Dąbrowska, 2001, 2004). Note that it is not possible on the dual-route approach to have more than one default, since this would require that the selection of each morpheme be governed by lexical properties of the verb class rather than syntactic category information. In fact, Ullman (2001, p. 43) explicitly states:

The affixation portion of these unproductive or partially productive transformations could, in principle, be computed by the rule system. . . here I will take the strong position that only fully productive transformations (i.e., defaults) can be learned and computed by the rule system: *morphological transformations that involve overt affixation but are not fully productive are computed solely in a structured associative memory.* (Our italics)

To fairly test the DP and single-route models, we tested children on verbs that take one of the *-si* or *-i* morphemes, and which were either productive, and so “regular”-like or nonproductive, and so “irregular”-like. We refer to regular-like verbs that take the *-si* suffix as *fully productive*, and regular-like verbs that take the *-i* suffix as *semi-productive*, due to the fact that the fusional suffixation process results in the changes to the stem. We refer to irregular-like verbs that result in qualitative stem changes (as in 10) as *stem change verbs*. Additionally, we directly tested children’s productive knowledge by testing them on novel verbs.

THE CURRENT STUDY

In the current study we tested the DP and the single-route models’ specific predictions about the relationship between procedural and declarative memory and language acquisition in 4–6-year-old children acquiring Finnish as a first language. The children were tested on productive and nonproductive verbs that take one of either the *-si* or *-i* suffix, and were also tested on novel verbs. The DP model predicts that children’s knowledge of productive real and novel verbs will be predicted by children’s procedural memory abilities, such that those with better procedural memory will more readily seize upon the regular pattern. The model predicts that children’s declarative memory will predict their performance on all other verb types. In contrast, the single-route approach predicts that memory only plays an indirect role in the production of complex morphological forms. Specifically, it predicts that declarative memory will predict vocabulary size, which will in turn predict the children’s morphological knowledge *in toto*.

METHOD

Participants

One-hundred and twenty-four monolingual Finnish children ($N = 124$) were recruited from kindergartens in Kotka, Southern Finland. They were aged between 4;0 and 6;7 ($M = 5;2$, $SD = 9.2$ months). The children had no language or cognitive impairments.

Materials and procedure

The children were tested on a battery of tests, including: (1) a test of procedural memory; (2) a test of declarative memory; (3) a test of receptive vocabulary; (4) a test of nonverbal ability; and (5) a test of past tense

knowledge. The tests were presented to the children in a pseudorandomised order to avoid any potential carryover effects. Each is described in turn.

Test of procedural memory

To measure procedural memory we used a children's version of Nissen and Bullemer's (1987) serial reaction time (SRT) task, adapted for use with preschool children by Lum et al. (2010a); see also Lum, Kidd, Davis, & Conti-Ramsden, 2010b). In this task participants implicitly learn a 10-item repeating sequence, which consists of a single visual stimulus that moves between four spatial locations on a computer screen. The only instruction provided to participants is to press one of four buttons on a response panel that matches the location of the visual stimulus. For example, if the stimulus appears in Location C, the participant is required to press Button C on the response panel. If the stimulus appears in Location A, the participant is required to press Button A, and so on. The 10-item repeating sequence is presented to participants over four blocks of 60 trials. In the final fifth block the visual stimulus appears in a random order for another 60 trials. The primary dependent variable of interest is the participants' reaction times (RTs). In healthy children (e.g., Thomas & Nelson, 2001) and adults (e.g., Daselaar, Rombouts, Veltman, Raaijmakers, & Jonker, 2003), RTs typically decrease as they progress through the blocks with the repeating sequence and increase on the random block. This increase is often referred to as a *rebound effect* (e.g., Knopman & Nissen, 1991), and is used to demonstrate whether procedural learning has occurred, since decreases in RTs observed over preceding blocks may represent practice effects (for more details see Lum et al., 2010a, 2010b).

The SRT task was presented to the children in the context of a computer game. The moving visual stimulus was a well-known cartoon character, and the children were told that the objective of the game was to press the button that corresponded to the location of the character as quickly as possible. The response panel was in fact a game pad commonly used in computer games, which has four buttons on the right-hand side arranged in a diamond shape, directly matching the locations in which the character could appear on the computer screen. The children therefore pressed the buttons using their right thumb.⁴ The experimenter explained the task to the children by pointing out the spatial correspondences between the four possible locations of the visual stimulus and the buttons on the game pad. Once the experimenter was sure

⁴ Lum et al. (2010a) showed that handedness is not related to performance on the task, presumably because most children have a fair amount of practice using game pads. Therefore handedness was not likely to affect our results.

that the child understood, she guided the child through 10 practice trials, and provided feedback when the child made an incorrect button press.

To ensure that the children had learned an implicit pattern, at the conclusion of the task we tested whether or not the children had any explicit awareness of the repeating pattern. The children were told that there was a pattern, and were asked to attempt to generate the pattern by pointing to the appropriate sequential locations on the computer screen, beginning with the upper-most middle location. No child generated more than 3 out of 10 correct sequential locations, showing that none of the children had explicitly remembered the pattern.

Key evidence supporting the SRT task as a measure of procedural learning comes from studies involving patients with basal-ganglia pathology. Research has shown that patients with Huntington's disease (Kim et al., 2004; Knopman & Nissen, 1991) and Parkinson's disease (Siegert, Taylor, Weatherall, & Abernethy, 2006) demonstrate a smaller rebound effect than controls, suggesting that they have a decreased ability to learn patterns implicitly. Furthermore, despite being a nonverbal task, some recent studies have shown that the task is both (1) related to syntactic processing in adults and children (Conway, Bauernschmidt, Huang, & Pisoni, 2010; Kidd, 2009), and (2) discriminates between normally developing children and children with SLI (Lum et al., 2010a; Tomblin et al., 2007). However, no study has yet shown that performance on the task is directly related to the processing of regular past tense, as explicitly predicted by the DP model. Thus the SRT was a crucial inclusion in our study, as it allowed us to assess the role of procedural learning in the acquisition of the past tense, and therefore test one of the main predictions of the DP model.

Test of declarative memory

An adapted version of the word-pairs subtest from the Children's Memory Scales (WP-CMS; Cohen, 1997) was used to measure declarative memory. Research has shown that performance on learning word pairs (WPs) is impaired following pathology associated with the left medial temporal lobe (Jones-Gotman, 1992); a major neural structure supporting declarative memory (Squire, Stark, & Clark, 2004). Therefore the WP-CMS enabled us to assess the contribution of the declarative memory system to the acquisition of vocabulary and past tense morphology.

In the task children learn a list of 10 WPs (e.g., *nurse-fire*). They are given three trials to learn the list. At the start of each trial the list of WPs is presented orally. Following this initial presentation children are presented with the first word of the pair (e.g., *nurse*) and asked to recall the second (e.g., *fire*). This procedure is followed for the second and third presentation of the WPs using a different presentation order. At the conclusion of the

third trial there is another recall task in which participants are asked to recall both words in the pair. The WPs task therefore produces two indices that measure declarative memory. Children's performance on this task was described by summing the total number of correct responses over the four recall trials.

We translated the test into Finnish in the following manner: whenever possible ($N = 11/20$ words) the Finnish counterpart of the original English test word was used (e.g., *baby–vauva*, *school–koulu*). When this could not be done due to differences in length of words in Finnish and English (e.g., *nurse–sairaanhoitaja*) or unfamiliarity to Finnish children (e.g., *mile*), we searched for words that: (1) had similar surface frequencies; (2) came from the same semantic category; and (3) was the same length as the item in the English test. The surface frequency of the words in the English test was searched for in the Manchester corpus (Theakston, Lieven, Pine, & Rowland, 2001) of the CHILDES data base (MacWhinney, 2000). Items of comparable frequency, semantics, and length (in syllables) were then extracted from the Kirjavainen-MPI Finnish child language corpus (Max Planck Institute for Evolutionary Anthropology, Leipzig). At the time the searches were conducted the corpus contained 277,000 word tokens. In general, it was fairly easy to match items on frequency and semantics; however, it was impossible to match for item length because there are very few monosyllabic Finnish words. Therefore, all Finnish words chosen were two syllables long. Despite this fact, the children's scores on the test still followed a normal distribution (see below), suggesting that we were able to capture a range of abilities.

Test of receptive vocabulary

The children were tested on an adapted version of the English *Peabody Picture Vocabulary Test* (PPVT; Dunn & Dunn, 2007). This is a receptive vocabulary test in which children are shown an array of four coloured pictures. The experimenter reads out the target word to them, and they are required to select the picture that matches the target word. The test becomes progressively more difficult; once children fail eight items within one block (of 12 items) the test is terminated. We created a truncated version ($N = 180$ test items in total) of the PPVT in Finnish. This was created so that, for the most part, the target item of the English test was translated into Finnish. However, when this was inappropriate (due to the Finnish equivalent of the word not corresponding to the English item in difficulty), we calculated the surface frequencies for words corresponding to the four pictures for those particular test items and selected the most appropriate pictures for our target words accordingly. There were quite a few occasions where we had to choose different items. Regardless, as with our translation of the WPs task, the

children's scores on the test followed a normal distribution, suggesting that once again we were able to capture a range of knowledge states.

Test of nonverbal ability

The Raven's Coloured Progressive Matrices (RCPM; Raven, 1998) was used to assess nonverbal reasoning. In this test children are presented with a series of stimulus pictures of abstract patterns. In each picture there is a piece missing; the child's task is to choose the missing piece that matches the pattern in the stimulus picture from an array of six possible alternatives. The decision to include a measure of nonverbal reasoning was motivated by our concern that potential associations found between the measures of memory and language functioning might reflect an association with intelligence. The children's raw scores from this test were used as a covariate in the proceeding analyses.

Test of past tense production

The children were tested using a "wug"-style past tense elicited production task (Berko, 1958). In the task, the children were told that they were going to see a series of characters performing actions, some of which would be "funny" (i.e., novel). For each item the children saw a picture on a laptop computer screen and simultaneously heard a pre-recorded test sentence describing the picture through headphones (for novel verbs, the pictures depicted novel actions; see Appendix 1 for example pictures). Following Lytinen (1988a, 1988b), the verbs were presented in an A-infinitive⁵ form and elicited in the past tense in sentences such as (11).

- (11) Niko tykkää/haluaa pelata. Eilenkin/äskengin/viimeksikin se ____.
Niko likes/wants/ to play. Yesterday/a moment ago/last time he also ____.

The benefit of the wug-test is that the children are provided with a sentential context, which unambiguously identifies the target as a verb, thus minimising any ambiguity regarding the syntactic category of novel verbs and any real verbs whose root also appears in other syntactic contexts, which is often inevitable given the restricted range of items on which children can be tested (e.g., *run*, *walk*, *draw*). Three practice verbs were administered before the testing began: 1 × *i-* "*kävellä*" (walk), 1 × *-si* or *-i* suffix "*piirtää*" (draw), and 1 × stem change, which could be taken as either *-si* or *-i* "*juosta-juoksi*" (run). All the practice items were from categories other than the two verb

⁵ The A-infinitive is not a base form like in English, since in Finnish verbs are always inflected. The A-infinitive, even though morphologically complex, is often the citation form of verbs.

categories used in the present study (i.e., they were drawn from different categories based on the 25 verb categories identified in Suomen Kielen Perussanakirja, 1994). The test verbs were presented in a random order selected by E-prime software (MacWhinney, James, Schunn, Li, & Schneider, 2001). If the child did not provide a response, produced the infinitive or present tense form, or produced a nontarget verb, the experimenter emphasised that the event took place before the current time and that the child had to use the same verb as they had heard. The test sentence and the corresponding picture were then played again one more time. Each child was tested on 60 out of total of 120 items, which were counterbalanced using a Latin-square design such that each verb was tested approximately an equal number of times in the sample. Each child was tested on 40 productive verbs, 8 nonproductive verbs, and 12 novel verbs, with half of the verbs in each category taking *-si* suffix and the other half taking the *-i* suffix. A greater number of productive and novel verbs were tested because it is on these verb types where the predictions of the DP and single-route models diverge. Testing was conducted over two sessions to avoid fatigue. An overview of the different verb categories is provided in Table 1. For a full list of the verbs and their frequency information see Appendix 2. The base and surface past tense frequencies for each (real) verb were counted from the CSC Language Bank newspaper corpora (131.4 million word tokens, <http://www.csc.fi/english>). In addition to the newspaper corpora, we searched for the past tense surface frequencies in a Finnish child corpus (Kirjavainen-Max Planck corpus). Phonological neighbourhood densities (PND) were searched in the Finnish dictionary (Suomen Kielen Perussanakirja, 1994). We adjusted the number of phonological neighbours by removing the items that 4–6-year olds were unlikely to know, as they would have been unlikely to affect the results if the children did not know them.

TABLE 1
Different verb categories tested

<i>Verb type</i>	<i>Suffix</i>	<i>Number of targets</i>
Real		
Productive	<i>-si</i>	40
Semi-productive	<i>-i</i>	40
Nonproductive	<i>-si</i>	8
Nonproductive	<i>-i</i>	8
Novel		
Productive	<i>-si</i>	12
Semi-productive	<i>-i</i>	12
Total		120

There are a few important things to note about our items shown in Appendix 2. Firstly, note that adult research into Finnish lexical access has shown that complex forms must occur over 100 times per million words in order to be stored as whole forms in a Finnish speaker's lexicon (Lehtonen et al., 2007; Lehtonen & Laine, 2003). Only one of our items (*voitti* [won], 217/million words) had a surface frequency this high. It is unclear at what surface frequency value children may store whole forms once they have productive knowledge of morphological paradigms. Our point here is that we chose our real verbs to be both (1) familiar to children aged 4–6 years and (2) at surface frequency levels that previous research with adults suggests would require composition of a stem and past tense suffix. This provides a strong test of the single-route approach, since the results cannot be explained by the fact that children may have simply memorised the past forms of the verbs tested. This means that hypothesised “regular”-like verbs cannot also profit from similar sounding high-frequency lexical neighbours that come from the same verb category, as has been shown in languages like English (e.g., Marchman, 1997).⁶ Secondly, the verbs were controlled for length, being 2–3 syllables and 6–8 phonemes long in their past form. Finally, we also tested children performance on novel verbs. These were created by changing the first phoneme (consonant) of a real Finnish verb (e.g., see Niemi, 2006). Initial bi- and trigram searches were conducted on these to ensure that the novel verbs reflected the phonotactics of real Finnish words. The novel verbs entered into putatively “regular” past tense processes, and so could be considered as novel versions of the *si*-suffix fully productive and *i*-suffix semi-productive verbs. The 24 novel verbs were paired with 24 novel actions.

The children's responses were transcribed during testing when visual information about articulation was available. In addition, the children's answers were audio recorded directly into a laptop computer using the SoundForge (Sonic Foundry) digital editing and recording software. Children's responses were coded as correct when they exactly matched the accepted past form (e.g., *pela|ta* → *pela|si*). Colloquial forms of the past tense were also coded as correct (e.g., *ootti* instead of *odotti*, *pelas* instead of *pelasi*). Any deviation from the correct form was coded as an error. The online transcriptions were checked against the recording and any discrepancies were corrected. Five percent (4.8%) of the children's answers were

⁶ In Appendix 2 we have listed the number of phonological “friends” each item has in Finnish. Note that none have phonological enemies, except for two nonproductive stem-change verbs. The dual-route approach predicts that, since our verbs are comparatively low in frequency and should not be stored as whole forms, the effect of neighbourhood density on our fully productive items should therefore be negligible.

coded for reliabilities. The agreement was high: 98.6% (355/360). Discrepancies were adjudicated by the second author.

RESULTS

We first present the descriptive statistics for all the dependent measures, after which we explicitly test the competing hypotheses of the dual and single-route approaches. Finally, we provide a brief discussion of the errors that the children made.

We first review the children's performance on the past tense elicitation task. The descriptive statistics for the children's performance on this task are presented in Figure 1.

Figure 1 shows that, for all verb categories, the children performed better on verbs that take the *-si* suffix than those that take the *-i* suffix. This was significant when comparing the "fully" productive *-si* and "semi-productive" *-i* verbs, $t(123) = 5.69$, $p < .001$, and the *-si* and *-i* suffix nonproductive stem change verbs, $t(123) = 3.67$, $p < .001$. However, the difference between the two suffix types on the novel verbs was not significant, $t(123) = 1.89$, $p = .062$. The data show that, across all verb types, the children were able to select the appropriate morpheme and correctly inflect the verb at least 50% of the time, suggesting that they understood that they were required to inflect the target verb in the past tense. The children's tendency to be more successful on verbs that take the *-si* could be interpreted to indicate that it is a possible default suffix in Finnish. However, the fact that the children did not consistently overgeneralise the novel verbs, for they have no lexical entry, suggests that this cannot be the case.

Figure 1. Mean proportion (and SEs) correct for each verb class.

TABLE 2
Summary statistics for measures of vocabulary, nonverbal ability, and declarative memory

<i>Measure</i>	<i>M</i>	<i>SD</i>	<i>Minimum</i>	<i>Maximum</i>
Vocabulary (PPVT) ^a	115.34	24.50	50	162
Nonverbal ability (RCPM) ^b	16.71	4.28	8	35
Declarative memory (WP) ^c	15.65	6.98	2	30

^aPossible range: 0–180; ^bpossible range: 0–36; ^cpossible range: 0–40; *N* = 124.

The descriptive statistics for the children's performance on the tests of vocabulary knowledge, nonverbal ability, and declarative memory (WPs) are shown in Table 2. All measures were normally distributed.

Finally, the children's performance on the procedural learning task was analysed. Four children failed to complete the task, and so we report on the data for the remaining 120 children. The SRT task yields two dependent measures: (1) an accuracy score, and (2) RTs. An analysis of the children's accuracy showed that they scored between 85 and 89% (*SD*s: 9–15%) correct across all blocks, suggesting that they paid attention to, and were successful on, the task. The primary dependent measure of interest is their RTs. In particular, for procedural learning to occur we need to observe a decrease in RTs across the first four blocks, in which the repeating pattern occurs. We then expect to see an overall increase in RTs for the random block, since children who have implicitly learnt the repeating pattern should experience interference when the stimulus appears randomly. Figure 2 shows the children's mean performance on each block of testing.

Figure 2 shows that, consistent with our prediction, the children showed a decrease in RTs from Blocks 1 to 4, but showed an increase from Block 4 to the random block. The children's RTs were entered into a five-way (block) repeated measures ANOVA. The main effect of block was significant, $F(2.21, 119) = 22.12$,⁷ $p < .001$, $\eta_p^2 = 0.157$. A summary of the post-hoc tests is shown in Table 3.

Table 3 shows that Block 1 differed significantly from every other block, as did Block 4. Importantly, Block 4 was significantly different from the random block, suggesting that there was an overall *rebound effect*. That is, the group data show that the children possessed the ability to learn the implicit pattern. For the individual differences analysis, each child's individual rebound effect was computed by subtracting their RT for Block 4 from their RT from the random block. However, since the SRT task produces RTs and we were computing individual differences analyses we

⁷ Greenhouse–Geisser corrected.

Figure 2. Mean RTs (and SEs) for children's performance on the SRT task.

treated the data further to reduce variability. To do this we converted every data point in Block 4 and the random block (i.e., those blocks that are used to compute the rebound effect) into a z -score for each participant. Then we computed the rebound effect on the basis of the means of the z -scores for Block 4 and the rebound block (i.e., $\text{Rebound} = \text{Random} - \text{Block 4}$). Positive scores were indicative of greater procedural learning.

The degree to which the multiple dependent measures were related is depicted in Table 4, which shows the simple correlations between the children's scores on the PPVT, WPs, RCPM, rebound effect, and age (in months).

Table 4 shows that all variables were positively correlated with age, although the measure of procedural memory, the rebound effect, was only weakly correlated. This is consistent with the finding that this memory system matures relatively early in development in comparison to declarative memory (Meulemans, van der Linden, & Perruchet, 1988; Thomas &

TABLE 3
Results from Bonferroni Post-hoc Tests on SRT RT data

Block	1	2	3	4	Random
Block 1	—				
Block 2	<.001	—			
Block 3	<.001	NS	—		
Block 4	<.001	.002	.004	—	
Random	.002	NS	NS	<.001	—

Note: NS, not significant.

TABLE 4
Correlations between the PPVT, RCPM, WP, and rebound effect

	<i>PPVT</i>	<i>RCPM</i>	<i>WP</i>	<i>Rebound</i>
Age	.609**	.600**	.371**	.134 [#]
PPVT		.555**	.427**	-.035
RCPM			.329**	.069
WPs				-.170*

* $p < .05$; ** $p < .001$; [#] $p < .10$.

Nelson, 2001). Vocabulary knowledge as measured by the PPVT was also significantly positively correlated with nonverbal intelligence (RCPM) and declarative memory (WPs). Nonverbal intelligence was also significantly correlated with declarative memory (WPs). Finally, declarative memory, as measured by the WPs task, was negatively correlated with implicit memory, as measured by the rebound effect.

The fact that the measure of procedural memory did not strongly correlate with the other dependent measures is not surprising. All the other measures are either measures of conscious learning and reasoning (WPs and RCPM), or of knowledge that is available to consciousness (PPVT). In contrast, as a measure of procedural learning the SRT task measures *implicit learning*, and so should not be available to conscious learning processes.

Testing the predictions of the declarative/procedural (DP) model

We now turn to our tests of the competing predictions of the DP and single-route models. Recall that the DP model argues for a direct association between procedural memory and performance on those aspects of inflectional morphology that are hypothesised to be rule-bound. Since it is difficult to identify a default suffix in Finnish, we tested this prediction by investigating the relationship between the children's performance on the procedural learning task (rebound) and their performance on the "regular"-like inflectional processes for both the *-si* and *-i* suffixes, using both real and novel verbs. In contrast, according to the DP model, declarative memory is hypothesised to predict performance on all other verbs that do not enter into putatively regular inflectional processes (i.e., stem change verbs).

The two predictions of the DP model were tested by looking for direct correlations between the children's performance on the memory tasks and their performance in the relevant verb types, after removing any variance associated with nonverbal intelligence and age. The dependent measure for procedural memory was the children's rebound effect which, like their

performance on the WPs task, was normally distributed. Finally, the variance associated with nonverbal ability and age was removed from the children's performance on the past tense task by regressing these variables onto the children's performance on the past tense task and saving the standardised residuals. The resulting data were normally distributed and used for all subsequent analyses. The relationship between the measures of procedural and declarative memory and the different categories of past tense are shown in Table 5.

Table 5 shows that procedural memory was not significantly correlated with the children's performance on any of the measures of past tense. This result is inconsistent with the predictions of the DP model.

Declarative memory was correlated with the children's performance on the stem change verbs, and weakly correlated with performance on the *si*-novel verbs, although this was not significant. The first result is consistent with the DP model, which predicts a direct association between declarative memory and irregular verbs.

Since our correlational analyses failed to reveal a role for procedural memory in the processing of regular-like forms, we decided to conduct an alternative analysis on the data in which we compared the rebound effects on the SRT task of the poor (bottom 25%) and good performers (top 25%) on the past tense task. Figure 3 shows the means and standard deviations of the bottom and top quartiles of the *si*-regular, *i*-regular, *si*-novel, and *i*-novel verbs. Figure 4 shows a comparison of the same groups' rebound effects.

Figures 3 and 4 show that, despite the fact that the children in bottom quartile on each "regular"-like category performed significantly worse on the past tense task than the children in the top quartile, in no comparison did the

TABLE 5
Correlations between procedural memory, declarative memory, and performance on each verb type (all *p*-values one-tailed)

	<i>si-regular</i> (<i>p</i>)	<i>i-regular</i> (<i>p</i>)	<i>si-novel</i> (<i>p</i>)	<i>i-novel</i> (<i>p</i>)	<i>si-stem</i> <i>change</i> (<i>p</i>)	<i>i-stem</i> <i>change</i> (<i>p</i>)
Procedural memory (rebound), <i>N</i> = 120	.028 (.38)	.072 (.22)	.037 (.35)	.039 (.34)	.057 (.27)	-.060 (.26)
Declarative memory (WPs), <i>N</i> = 124	.075 (.21)	.114 (.11)	.148 [#] (.051)	.106 (.12)	.205* (.011)	.201* (.013)

**p* < .05; [#]*p* < .10.

Figure 3. Means (and SEs) for children who were in the top and bottom quartile of performance on the regular-like verbs in the PT task (** $p < 0.001$).

children's rebound effect differ [*si*-regular: past tense task: $Z = 6.93$, $p < .001$; rebound: $t(58) = 0.32$, $p = .749$; *i*-regular: past tense task: $t(58) = 15.31$, $p < .001$; rebound: $t(58) = 0.048$, $p = .962$; *si*-novel: past tense task: $Z = 7.12$, $p < .001$; rebound: $t(58) = 0.60$, $p = .36$; *i*-novel: past tense task: $Z = 3.55$, $p < .001$; rebound: $t(58) = 0.78$, $p = .439$].⁸

Testing the predictions of the single-route model

The single-route approach predicts that declarative memory predicts vocabulary size, which in turn predicts performance on all verb types. This

Figure 4. Mean (and SEs) rebound effects for children who were in the top and bottom quartile of performance on regular-like verbs.

⁸ Nonparametric Wilcoxon-signed tests were computed for the *si*-regular, *si*-novel, and *i*-novel conditions because there was no variation in the top quartiles in their performance on the past tense task for these conditions.

TABLE 6
Tests of direct and indirect effects between declarative memory, vocabulary, and past tense knowledge

Verb category	Direct effect of vocabulary on past tense knowledge			Indirect effect of declarative memory on past tense knowledge	
	Standard coefficient	t-value	p-value	z-value	p-value
si-regular	.310	3.61	<.001	2.3	.01*
i-regular	.342	4.02	<.001	2.4	.008**
si-stem	.287	3.31	.001	2.2	.014*
i-stem	.215	2.43	.017	1.9	.03*
si-novel	.344	4.05	<.001	2.4	.008**
i-novel	.417	5.07	<.001	2.6	.005**

* $p < .05$; ** $p < .01$; $N = 124$.

prediction was tested using a series of tests of direct and indirect effects. Direct effects were tested using standard linear simple regression. The indirect effect of declarative memory on past tense knowledge was tested using the Sobel Test (1982), which is a standard (and conservative) test of mediation. Note, however, we are not testing for full mediation in our model, since this would require declarative memory to directly predict morphological knowledge in every instance, which we have already shown is not the case. Therefore we can only test for the presence of an indirect effect of declarative memory on morphological knowledge, via the relationship that both have with vocabulary knowledge. The direct association between declarative memory and vocabulary was significant ($\beta = .259$, $t = 2.96$, $p = .004$). The results from the tests of direct and indirect effects for each verb category are shown in Table 6.

There are two things to note from Table 6. Firstly, all direct associations between vocabulary size and performance on the past tense task are significant. Secondly, in every instance, the indirect relationship between declarative memory and performance on the past tense task was also significant, fully supporting the predictions of the single-route model.

Children’s past tense errors

The overall error proportion was 21.1% ($N = 1,569/7,440$), of which 42% were incorrect past tense responses ($N = 669$). Several types of past tense errors were found. Regularisation errors were made with both past tense suffixes (i.e., *si*-for-*i*; e.g., *voitta*|*si* and *selo*|*s* instead of *voitt*|*i* and *selost*|*i*, respectively [$N = 120$]; *i*-for-*si*; e.g., *viitta*|*i* and *ohja*|*i* instead of *viitta*|*si* and *ohja*|*si*, respectively [$N = 52$]). The children also produced stem change errors

relatively frequently ($N = 248$). Errors to the stem were most commonly over-regularisation errors, whereby the children inflected a nonproductive (i.e., qualitative stem change) verb without changing the stem (i.e., as if these were productive or semi-productive verbs; e.g., *mulla*|*ta*-**mulla*|*si* instead of *multa*|*si* or *madel*|*la*-**madel*|*si* instead of *matel*|*i*). This explains why the children's performance on the nonproductive stem change verbs was comparatively low. Additionally, for two verbs (*istahtaa-istaht*|*i* [to sit down casually] and *hypähtää-hypäht*|*i* [to spring]) the children sometimes exchanged the stem into a semantically and phonetically extremely similar verbs, *istui* (sat down; $N = 13.1\%$ of responses to *istahti*) and *hyppäsi* (jumped; 8.2% of responses to *hypähti*), respectively. This is likely to be because these two target verbs are more morphologically complex than (1) the items the children sometimes changed them into and (2) the test items in general. The children also produced consonant (and vowel) length errors ($N = 45$) in the past tense forms. These occurred most commonly with *-si* suffix verbs, which exhibit consonant gradation. However, some errors were also made with *-i* suffix verbs, which do not show this (e.g., **lorrotti* instead of *lorotti* [$N = 1$] and **tykitti* instead of *tykitti* [$N = 2$]). One-hundred and five responses were coded as "other past tense errors". In these the past tense suffix was overtly present but the base of the word was clearly incorrect (e.g., **pilotti* instead of *peruutti* or **lasketti*/**lapsistis* instead of *lasvitti*). The children also produced past tense forms of nontarget verbs ($N = 103$). These most commonly consisted of errors in which the child produced phonetically distinct yet semantically related verb (e.g., *otti* [took] instead of *nappasi* [caught]). However, with a small number of target verbs a semantically different but similar sounding verb was produced in the past tense by some children (e.g., *pelasi* [played] instead of *pelkäsi* [was scared of; $N = 18$], *jäähdytti* [cooled down] instead of *jäädytti* [froze; $N = 2$]).

In addition to past tense errors, the children produced the following error types: (1) no response ($N = 19$); (2) an A-infinitive form of the target verb (i.e., no change; $N = 519$); (3) present tense responses of target and nontarget verbs ($N = 186$ and 82 , respectively); and (4) nonword responses in a nonpast tense form, e.g., **luvattaa* for the target *lupasi* ($N = 94$).

DISCUSSION

In the current study we investigated the role of procedural and declarative memory in the acquisition of past tense morphology in Finnish, a highly inflected language from the Finno-Ugric language family. Two competing models of acquisition and processing were tested: (1) the DP model (Ullman, 2001, 2004), which predicts that the procedural and declarative memory systems support the acquisition and processing of putatively "regular" and

“irregular” forms, respectively, and (2) the single-route approach, which, by virtue of the argument that morphological knowledge is an emergent property of the lexicon (Marchman & Bates, 1994), predicts that declarative memory should predict vocabulary knowledge, which should in turn predict morphological knowledge. Finnish is an ideal language in which to test the competing predictions of these theories because its highly inflected nature necessitates that the production of most complex forms involves the concatenation of stem and suffix. This, combined with the fact that Finnish contains two past tense allomorphs, allowed us to tease apart the two approaches in a manner that is not possible when studying English. Our results were most consistent with the single-route approach: in every instance we found a direct positive and significant relationship between declarative memory and vocabulary size, which in turn predicted the children performance on every verb type. The indirect relationships between declarative memory and past tense knowledge were also significant in every instance.

Our results replicate and extend the data reported by Lum and Kidd (2010), who found the similar results in an English-speaking sample of children in the same age range. The data from the Finnish children strengthen and further refine the single-route account. Notably, even in cases where the storage of whole forms is potentially beyond the capacity of declarative memory because the surface forms may not occur often enough, we still observed a significant relationship between lexical and morphological knowledge. Even more importantly, when children were tested on novel verbs, forms for which they have no lexical entry, we still observed the same relationship. The data therefore provide further evidence for the strong and enduring relationship between the lexicon and grammar during language acquisition, and argue against dual-system accounts that partition grammatical and lexical knowledge into two distinct systems.

The novel verb data are particularly illuminating. The children performed consistently well on both past tense suffix types, immediately ruling out the possibility that they process novel forms using a default strategy. Instead, the fact that they consistently selected the appropriate morpheme for each stem suggests that they attend to item-level properties of the verb stem in order to select the appropriate allomorph. The fact that this was related to their lexical knowledge is likely to reflect the fact that those children who have greater vocabulary knowledge are likely to have either (1) more abstract knowledge of the past tense in the form of more elaborate and abstract product- and source-oriented schemas (Bybee & Slobin, 1982), or (2) a greater set of verb exemplars from which they can draw in order to make categorisation decisions about unencountered forms.

More broadly, the data are consistent with the close relationship observed between lexical and grammatical development in younger children, and

extend this finding to older preschool children (Bates & Goodman, 1997; Caselli et al., 1999; Maital et al., 2000; Marchman et al., 2004; Nicoladis et al., 2007; Szagun et al., 2006; Thordardottir et al., 2002). Beyond the demonstration of this strong relationship, the precise nature of the interaction between the lexicon and grammar is unclear. One long-standing assumption was that lexical knowledge was a developmental precursor to the development of grammatical knowledge (Bates & Goodman, 1997; Dixon & Marchman, 2007), although other studies have reported more bidirectional developmental trajectories (Anisfeld, Rosenberg, Hoberman, & Gasparini, 1998; Dionne, Dale, Boivin, & Plomin, 2003; Van Geert, 1991). Dixon and Marchman (2007) analysed the MacArthur-Bates Child Development Inventory (Fenson et al., 2007) norming data, a large data set ($N = 1,461$) of parental reports of children's linguistic development, from age 16 to 30 months. Using a nonlinear mapping technique (Dixon, 2005), they observed the expected curvilinear relationship between the lexicon and grammar that had been observed previously (Marchman & Bates, 1994). However, further analyses raised the possibility that the nonlinear relationship between the two measures could be explained by the nonlinear relationship between the measure of grammatical knowledge and the children's underlying grammatical knowledge. That is, the measure of grammatical knowledge varied in sensitivity across development. This raises the possibility that lexical and grammatical knowledge develop synchronously, rather than the grammatical knowledge being deterministically related to lexical knowledge.

In our data we observed a direct effect of vocabulary on the production of correct past tense forms, but cannot comment on whether a deterministic relationship holds between lexical knowledge and grammatical productivity because our data are correlational. However, we suggest that results from other areas of psycholinguistics provide support for an intimate and nontrivial relationship between lexical and grammatical knowledge. Beginning with very early multi-word speech there is a demonstrated link between lexical and syntactic knowledge (e.g., Lieven, Pine, & Baldwin, 1997), which seems to be supported by the fact that children store multi-word utterances and make computations over these stored sequences (Bannard, Lieven, & Tomasello, 2009; Bannard & Matthews, 2008; Kirjavainen, Theakston, Lieven, & Tomasello, 2009; Lieven, Behrens, Speares, & Tomasello, 2003). Children's and adults' sentence processing has been shown to be influenced by lexical constraints on interpretation (e.g., Kidd, Lieven, & Tomasello, 2006; MacDonald, Pearlmutter, & Seidenberg, 1994; Snedeker & Trueswell, 2004). The question is whether or not these two systems simply interface, as the dual-system account holds (e.g., Pinker, 1991; Ullman, 2001, 2004), or whether they can be argued to be linguistic knowledge that exists along a continuum (e.g., Bates & MacWhinney, 1989; Bybee, 2006; Goldberg, 2006; MacWhinney, 1998). We suggest that the weight of evidence, including the

results of our study, supports the latter account. Indeed, not only do our results strongly support the single system account, but also our use of Finnish as a target language shows that it is very difficult to fit the theoretical primitives of the dual-system approach to languages beyond the narrow range that have been studied (mainly Indo-European).

A final issue concerns the role of procedural memory in the acquisition and processing of language. Although our results revealed no role for procedural memory in the acquisition of morphology, we do not take these results as being terminal for the DP model of language. Rather, we suggest that inflectional morphology is not a good testing ground for the theory. Instead, procedural or implicit processes are more likely to play a role in the sequencing of linguistic information at the level of the sentence rather than the word. For instance, there is a general consensus in the syntactic priming literature that priming and therefore sentence production is implicit (e.g., Chang, Dell, & Bock, 2006; Ferreira, Bock, Wilson, & Cohen, 2008), and although clearly sentence production must interact with declarative knowledge in the form of lexical access, we suggest that the sequencing of lexical information is a good candidate for linguistic phenomena that could come under procedural control.

There is some support for this assertion. Conway et al. (2010) showed that performance on a visual sequencing task similar to the SRT task used in the present study significantly correlated with adult participants' ability to predict the next word in a sentence under degraded input. They concluded that their results suggest that (modality general) sequencing abilities are essential for acquiring long-term knowledge about the sequential structure of language. In a similar study conducted with children aged 4–6 years, Kidd (2009) showed that children's rebound effect in the same SRT task used in the current study predicted children's tendency to be primed in a syntactic priming task that targeted the use of the English passive structure.

Given our focus in this paper on Finnish, a natural question that arises is what role might procedural memory play in the acquisition of morphologically rich languages that have relatively free word order? We can envisage two ways in which procedural learning could support acquisition in languages like Finnish. Firstly, procedural memory could support morphological acquisition and processing in cases where morpheme stacking results in morphologically complex words that mark multiple grammatical features. Example (1), repeated here as (12), provides one simple scenario.

- (12) pela|si|tte|ko (*Did you play?*)
 play|past tense|1pl|interrogative clitic

Although we found no significant evidence to suggest that procedural memory supports the formation of the past tense in Finnish, this does not

rule out that it could be involved in larger grammatical sequences that involve the sequencing of information that is not immediately related to the verb. This is an empirical question that awaits further research. Secondly, procedural memory might only be involved in sequencing words at the sentential level. However, since in highly inflected languages several semantically distinct items (or even a whole sentence) are merged into one word that, in less inflected languages, would be represented by separate words, we propose that both suggestions here are worthy of further investigation.

CONCLUSION

We have shown that, consistent with data from English-speaking children, the acquisition of Finnish past tense morphology is closely related to vocabulary development, which is predicted by their declarative memory. Therefore, even in languages where verbs can have a comparatively high number of surface forms, children's acquisition is still dependent on the item-level properties of verbs, which is consistent with the single-route approach to language.

REFERENCES

- Albright, A., & Hayes, B. (2003). Rules versus analogies in the English past tenses: A computational/empirical study. *Cognition*, 90, 119–161.
- Anisfeld, N., Rosenberg, E. S., Hoberman, M. J., & Gasparini, D. (1998). Lexical acceleration coincides with the onset of combinatorial speech. *First Language*, 18, 165–184.
- Bannard, C., & Matthews, D. (2008). Stored word sequences in language learning: The effect of familiarity on children's repetition of four-word combinations. *Psychological Science*, 19, 241–248.
- Bannard, C., Lieven, E., & Tomasello, M. (2009). Modelling children's early grammatical knowledge. *Proceedings of the National Academy of Sciences*, 106, 17284–17289.
- Bates, E., & Goodman, J. C. (1997). On the inseparability of grammar and the lexicon: Evidence from acquisition, aphasia, and real-time processing. *Language and Cognitive Processes*, 12, 507–584.
- Bates, E., & MacWhinney, B. (1989). Functionalism and the competition model. In B. MacWhinney & E. Bates (Eds.), *The crosslinguistic study of sentence processing* (pp. 3–73). Cambridge, UK: Cambridge University Press.
- Berko, J. (1958). The child's learning of English morphology. *Word*, 14, 150–177.
- Bird, H., Lambon-Ralph, M. A., Seidenberg, M., McClelland, J., & Patterson, K. (2003). Deficits in phonology and past tense morphology. *Journal of Memory and Language*, 48, 502–526.
- Braber, N., Patterson, K., Ellis, K., & Lambon-Ralph, M. A. (2005). The relationship between phonological and morphological deficits in Broca's aphasia: Further evidence from errors in verb inflection. *Brain and Language*, 92, 278–287.
- Bybee, J. (1995). Regular morphology and the lexicon. *Language and Cognitive Processes*, 10, 425–455.

- Bybee, J. (2006). From usage to grammar: The minds response to repetition. *Language*, 82, 323–355.
- Bybee, J., & Slobin, D. I. (1982). Rules and schemas in the development and use of the English past tense. *Language*, 58, 265–289.
- Caselli, C., Casadio, P., & Bates, E. (1999). A comparison of the transition from first words to grammar in English and Italian. *Journal of Child Language*, 26, 69–111.
- Chang, F., Dell, G., & Bock, J. K. (2006). Becoming syntactic. *Psychological Review*, 113, 234–272.
- Clahsen, H. (1999). Lexical entries and rules of language: A multidisciplinary study of German inflection. *Behavioral and Brain Sciences*, 22, 991–1060.
- Cohen, M. J. (1997). *Children's Memory Scales*. London: The Psychological Corporation.
- Conway, C. M., Bauernschmidt, A., Huang, S. S., & Pisoni, D. B. (2010). Implicit statistical learning in language processing: Word predictability is the key. *Cognition*, 114, 356–371.
- Dabrowska, E. (2001). Learning a morphological system without a default. *Journal of Child Language*, 28, 545–574.
- Dabrowska, E. (2004). Rules or schemas? Evidence from Polish. *Language and Cognitive Processes*, 19, 225–271.
- Dabrowska, E. (2008). The effects of frequency and neighbourhood density on adult speakers' productivity with Polish case inflections: An empirical test of usage-based approaches to morphology. *Journal of Memory and Language*, 58, 931–951.
- Daelemans, W. (2002). A comparison of analogical modelling of language to memory-based language processing. In R. Skousen, D. Lonsdale, & D. B. Parkinson (Eds.), *Analogical modelling: An exemplar-based approach to language* (pp. 157–179). Amsterdam: John Benjamins.
- Daselaar, S. M., Rombouts, S. A., Veltman, D. J., Raaijmakers, J. G., & Jonker, C. (2003). Similar network activated by young and old adults during the acquisition of a motor sequence. *Neurobiology of Aging*, 24, 1013–1019.
- Dionne, G., Dale, P. S., Boivin, M., & Plomin, R. (2003). Genetic evidence for bidirectional effects of early lexical and grammatical development. *Child Development*, 74, 394–412.
- Dixon, J. A. (2005). Strong tests of development ordering hypotheses: Integrating evidence from the second moment. *Child Development*, 76, 1–23.
- Dixon, J. A., & Marchman, V. A. (2007). Grammar and the lexicon: Developmental ordering in language acquisition. *Child Development*, 78, 190–212.
- Dunn, L., & Dunn, D. (2007). *Peabody Picture Vocabulary Test* (4th ed.). San Antonio, TX: Pearson Education.
- Eichenbaum, H., & Cohen, N. J. (2001). *From conditioning to conscious reflection: Memory systems of the brain*. New York: Oxford University Press.
- Fenson, L., Marchman, V. A., Thal, D., Dale, P. S., Reznick, J. S., & Bates, E. (2007). *MacArthur-Bates communicative development inventories: User's guide and technical manual* (2nd ed.). Baltimore, MD: Brookes.
- Ferreira, V. S., Bock, J. K., Wilson, M. P., & Cohen, N. J. (2008). Memory for syntax despite amnesia. *Psychological Science*, 19, 940–946.
- Goldberg, A. (2006). *Constructions at work: The nature of generalization in language*. Oxford, UK: Oxford University Press.
- Hakulinen, A., Vilkkumäki, M., Korhonen, R., Koivisto, V., Heinonen, T. R., & Alho, I. (2005). *Iso Suomen Kielioppi* [The large grammar of Finnish]. Helsinki: Suomalaisen Kirjallisuuden Seura.
- Hartshorne, J. K., & Ullman, M. (2006). Why girls say 'holded' more than boys. *Developmental Science*, 9, 21–32.
- Joanisse, M. F., & Seidenberg, M. S. (1999). Impairments in verb morphology following brain injury: A connectionist model. *Proceedings of National Academy of Sciences USA*, 96, 7592–7597.
- Jones-Gotman, M. (1992). Presurgical neuropsychological evaluation for localization and lateralization of seizure focus. In H. Luders (Ed.), *Epilepsy surgery* (pp. 469–485). New York: Raven Press.

- Kidd, E. (2009, March). *An assessment of the contributions of the implicit and explicit memory systems to syntactic priming: Evidence from acquisition*. Poster session presented at the 22nd annual CUNY Conference on Human Sentence Processing, UC Davis, CA.
- Kidd, E., Lieven, E., & Tomasello, M. (2006). Examining the role of lexical frequency in children's acquisition of sentential complements. *Cognitive Development*, 21, 93–107.
- Kidd, E., & Lum, J. (2008). Sex differences in past tense overregularization. *Developmental Science*, 11, 882–889.
- Kim, J., Reading, S. A. J., Brashers-Krug, T., Calhoun, V. D., Ross, C. A., & Pearlson, G. D. (2004). Functional MRI study of a serial reaction time task in Huntington's disease. *Psychiatry Research: Neuroimaging*, 131, 23–30.
- Kirjavainen, M., Nikolaev, A., & Kidd, E. (2010). *The effects of frequency and neighbourhood density on the acquisition of past tense morphology by Finnish-speaking children*. Manuscript submitted for publication.
- Kirjavainen, M., Theakston, A. L., Lieven, E. V., Tomasello, M. M. (2009). 'I want hold Postman Pat': An investigation into the acquisition of infinitival marker 'to'. *First Language*, 39, 313–339.
- Knopman, D., & Nissen, M. J. (1991). Procedural learning is impaired in Huntington's disease: Evidence from the serial reaction time task. *Neuropsychologia*, 29, 245–254.
- Lehtonen, M., Cunillera, T., Rodríguez-Fornells, A., Hultén, A., Tuomainen, J., & Laine, M. (2007). Recognition of morphologically complex words in Finnish: Evidence from event-related potentials. *Brain Research*, 1148, 123–137.
- Lehtonen, M., & Laine, M. (2003). How word frequency affects morphological processing in monolinguals and bilinguals. *Language and Cognition*, 6, 213–225.
- Lieven, E., Behrens, H., Speares, J., & Tomasello, M. (2003). Early syntactic creativity: A usage-based approach. *Journal of Child Language*, 30, 333–370.
- Lieven, E., Pine, J., & Baldwin, G. (1997). Lexically-based learning and the development of grammar in early multi-word speech. *Journal of Child Language*, 24, 187–219.
- Lum, J. A. G., Gelec, C., & Conti-Ramsden, G. (2010a). Procedural and declarative memory in children with and without specific language impairment. *International Journal of Language and Communication Disorders*, 45, 96–107.
- Lum, J. A. G., & Kidd, E. (2010). *The relationship between memory, past tense and vocabulary in typically developing children*. Manuscript submitted for publication.
- Lum, J. A. G., Kidd, E., Davis, S., & Conti-Ramsden, G. (2010b). Longitudinal study of declarative and procedural memory in preschool children. *Australian Journal of Psychology*. Advance online publication. DOI: 10.1080/00049530903150547
- Lyytinen, P. (1988a). *Suomen kielen taivutusmuotojen hallinta 2–9-vuotiailla* [Finnish 2–9-year-olds' proficiency with inflections] (Report no. 297). Unpublished manuscript, Department of Psychology, University of Jyväskylä.
- Lyytinen, P. (1988b). *Morfologiatesti* [Morphology test] (Report no. 298). Unpublished manuscript, Department of Psychology, University of Jyväskylä.
- MacDonald, M. C., Pearlmutter, N. J., & Seidenberg, M. S. (1994). Lexical nature of syntactic ambiguity resolution. *Psychological Review*, 101, 676–703.
- MacWhinney, B. (1998). Models of the emergence of language. *Annual Review of Psychology*, 49, 199–227.
- MacWhinney, B. (2000). *The CHILDES project*. Hillsdale, NJ: Erlbaum.
- MacWhinney, B., James, J. S., Schunn, C., Li, P., & Schneider, W. (2001). STEP – a system for teaching experimental psychology using E-prime. *Behavior Research Methods, Instruments and Computers*, 33, 287–296.
- Maital, S., Dromi, E., Sagi, A., & Bornstein, M. (2000). The Hebrew communicative development inventory: Language specific properties and crosslinguistic generalizations. *Journal of Child Language*, 21, 339–366.

- Marchman, V. A. (1997). Children's productivity in the English past tense: The role of frequency, phonology, and neighbourhood structure. *Cognitive Science*, 21, 283–304.
- Marchman, V. A., & Bates, E. (1994). Continuity in lexical and morphological development: A test of the critical mass hypothesis. *Journal of Child Language*, 21, 331–366.
- Marchman, V. A., Martínez-Sussmann, C., & Dale, P. S. (2004). The language-specific nature of grammatical development: Evidence from bilingual language learners. *Developmental Science*, 7, 212–224.
- Marchman, V. A., Saccuman, C., & Wulfeck, B. (2004). Productive use of the English past tense in children with focal brain injury and specific language impairment. *Brain and Language*, 88, 202–214.
- Marchman, V. A., Wulfeck, B., & Ellis Weismer, S. (1999). Productivity of past tense in children with normal language and specific language impairment. *Journal of Speech, Language and Hearing Research*, 42, 206–219.
- Marcus, G. F., Brinkmann, U., Clahsen, H., Wiese, R., & Pinker, S. (1995). German inflection: The exception that proves the rule. *Cognitive Psychology*, 29, 189–256.
- Marcus, G. F., Pinker, S., Ullman, M. T., Hollander, M., Rosen, T., & Xu, F. (1992). Over-regularization in language acquisition. *Monographs of the Society for Research in Child Development*, 57(228).
- Matthews, D. E., & Theakston, A. L. (2006). Errors of omission in English-speaking children's production of plurals and the past tense: The effects of frequency, phonology, and competition. *Cognitive Science*, 30, 1027–1052.
- McClelland, J. L., & Patterson, K. (2002). Rules or connections in past-tense inflections: What does the evidence rule out? *Trends in Cognitive Sciences*, 6, 465–472.
- Meulemans, T., van der Linden, M., & Perruchet, P. (1988). Implicit sequence learning in children. *Journal of Experimental Child Psychology*, 69, 199–221.
- Nicoladis, E., Palmer, A., & Marentette, P. (2007). The role of type and token frequency in using past tense morphemes correctly. *Developmental Science*, 10, 237–254.
- Niemi, J. (2006). Paradigm competition: an experimental note on Finnish verbs. In M. Suominen, A. Arppe, A. Airola, O. Heinämäki, M. Miestamo, U. Määttä, J. Niemi, K. K. Pitkänen, & K. Sinnemäki (Eds.), *A man of measure: Festschrift in honour of Fred Karlsson on his 60th birthday* [Special supplement to SKY Journal of Linguistics, Vol. 19] (pp. 345–356). Turku: The Linguistic Association of Finland.
- Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology*, 19, 1–32.
- Pinker, S. (1991). Rules of language. *Science*, 253, 530–535.
- Pinker, S., & Ullman, M. T. (2002). The past and future of past tense. *Trends in Cognitive Sciences*, 6, 456–463.
- Prado, E., & Ullman, M. (2009). Can imageability help us draw the line between storage and computation? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 35, 849–866.
- Prasada, S., & Pinker, S. (1993). Generalisation of regular and irregular morphological patterns. *Language and Cognitive Processes*, 8, 1–56.
- Plunkett, K., & Marchman, V. A. (1991). U-shaped learning and frequency effects in a multi-layered perceptron: Implications for child language acquisition. *Cognition*, 38, 43–102.
- Plunkett, K., & Marchman, V. A. (1993). From rote learning to system building: Acquiring verb morphology in children and connectionist nets. *Cognition*, 48, 21–69.
- Raven, J. (1998). *Raven's Progressive Matrices and Vocabulary Scales*. London: The Psychological Corporation.
- Rumelhart, D., & McClelland, J. (1986). On learning the past tense of English verbs. In D. E. Rumelhart & J. L. McClelland (Eds.), *Parallel distributed processing: Explorations in the microstructure of cognition (Vol. 2): Psychological and biological models* (pp. 272–326). Cambridge, MA: MIT Press.

- Skousen, R. (1989). *Analogical modeling of language*. Dordrecht: Kluwer.
- Skousen, R. (2003). Analogical modeling: Exemplars, rules, and quantum computing. *Proceedings of the Berkeley Linguistics Society*, 29, 425–439.
- Siebert, R. J., Taylor, K. D., Weatherall, M., & Abernethy, D. A. (2006). Is implicit sequence learning impaired in Parkinson's disease? A meta-analysis. *Neuropsychology*, 20, 490–495.
- Sobel, M. E. (1982). Asymptotic confidence intervals for indirect effects in structural equation models. In S. Leinhardt (Ed.), *Sociological methodology 1982* (pp. 290–312). Washington, DC: American Sociological Association.
- Snedeker, J., & Trueswell, J. C. (2004). The developing constraints on parsing decisions: The role of lexical-biases and referential scenes in child and adult sentence processing. *Cognitive Psychology*, 49, 238–299.
- Squire, L. R., Stark, C. E., & Clark, R. E. (2004). The medial temporal lobe. *Annual Review of Neuroscience*, 27, 279–306.
- Stolt, S., Haataja, L., Lapinleimu, H., & Lehtonen, L. (2009). Associations between lexicon and grammar at the end of the second year in Finnish children. *Journal of Child Language*, 36, 779–806.
- Suomen kielen perussanakirja*. (1994). [Basic Finnish Language Dictionary]. Helsinki: Edita Oyj.
- Szagan, G., Steinbrink, C., Franik, M., & Stumper, B. (2006). Development of vocabulary and grammar in young German-speaking children assessed with a German language development inventory. *First Language*, 26, 259–280.
- Theakston, A., Lieven, E., Pine, J., & Rowland, C. (2001). The role of performance limitations in the acquisition of verb argument structure. *Journal of Child Language*, 28, 127–152.
- Thomas, K. M., & Nelson, C. A. (2001). Serial reaction time learning in preschool- and school-age children. *Journal of Experimental Child Psychology*, 79, 364–387.
- Thordardottir, E., Weismer, S., & Evans, J. (2002). Continuity in lexical and morphological development in Icelandic and English-speaking 2-year-olds. *First Language*, 22, 2–28.
- Toivainen, J. (1997). The acquisition of Finnish. In D. I. Slobin (Ed.), *The crosslinguistic study of language acquisition* (Vol. 4, pp. 87–182). Mahwah, NJ: Lawrence Erlbaum.
- Tomasello, M. (1992). *First verbs: A case study of early grammatical development*. Cambridge: Cambridge University Press.
- Tomblin, J. B., Mainela-Arnold, E., & Zhang, X. (2007). Procedural learning in adolescents with and without specific language impairment. *Language Learning and Development*, 3, 269–293.
- Ullman, M. T. (2001). The declarative/procedural model of lexicon and grammar. *Journal of Psycholinguistic Research*, 30, 37–69.
- Ullman, M. T. (2004). Contributions of memory circuits to language: the declarative/procedural model. *Cognition*, 92, 231–270.
- Ullman, M. T., Corkin, S., Coppola, M., Hickock, G., Growden, J. H., Koroshetz, W. J., & Pinker, S. (1997). A neural dissociation within language: Evidence that the mental dictionary is part of declarative memory, and that grammatical rules are processed by the procedural system. *Journal of Cognitive Neuroscience*, 9, 266–276.
- Ullman, M., & Pierpont, E. L. (2005). Specific language impairment is not specific to language: The procedural deficit hypothesis. *Cortex*, 41, 399–433.
- Van Geert, P. (1991). A dynamic systems model of cognitive and language growth. *Psychological Review*, 98, 3–53.
- Wallentin, M. (2009). Putative sex differences in verbal abilities and language cortex: A critical review. *Brain and Language*, 108, 175–183.
- Woollams, A. M., Joanisse, M., & Patterson, K. (2009). Past-tense generation from form versus meaning: Behavioural data and simulation evidence. *Journal of Memory and Language*, 61, 55–76.

APPENDIX 1. EXAMPLES OF TEST PICTURES

Example Pictures of Real Verbs

Hypätä ('to jump')

Example Pictures of Novel Verbs

Märäyttää ('to meek')

Työnnellä ('to push')

Keinittää ('to glorp').

APPENDIX 2. FREQUENCY AND PHONOLOGICAL
NEIGHBOURHOOD DENSITY STATISTICS FOR THE ITEMS
USED IN THE STUDY

Note: Frequency estimates were taken from (1) the CSC Language Bank newspaper corpora (131.4 million word tokens, www.csc.fi/english) and (2) the Kirjavainen-Max Planck Piia corpus of one child collected longitudinally between ages 1;7–4;0. At the time of the searches the corpus constituted 277,000 word tokens. Phonological neighbourhood densities (PND) estimates were taken from a Finnish dictionary (*Suomen Kielen Perussanakirja*, 1994) adjusted by the second author and another Finnish speaker by removing any neighbours that children aged 4–7 years were unlikely to know.

TABLE A1
Productive verbs (*si*-suffix), their base and surface frequencies and adjusted
phonological neighbourhood densities

<i>Infinitive form</i>	<i>Past tense form</i>	<i>Gloss</i>	<i>Base, freq/mil</i>	<i>Past tense surface, freq/mil</i>	<i>Past tense surface frequency, Piialmil</i>	<i>Adjusted PND</i>
pelata	pelasi	to play	472.38	70.99	14.44	3
herätä	heräsi	to wake up	76.45	9.95	79.42	2
vastata	vastasi	to answer	479.34	55.65	0	2
leikata	leikkasi	to cut	100.60	3.74	21.66	3
viitata	viittasi	to put hand up/ to refer to	101.00	16.64	0	2
kerätä	keräsi	to collect	206.57	34.69	0	2
haukata	haukkasi	to bite	3.00	0.46	18.05	2
halata	halasi	to hug	3.59	0.46	14.44	2
pilata	pilasi	to ruin	26.57	4.61	0	2
hukata	hukkasi	to lose	13.48	3.32	0	2
pakata	pakkasi	to pack	24.35	1.58	3.61	4
selata	selasi	to flick through	4.37	0.24	0	3
jumpata	jumppassi	to do gymnastics	1.95	0.04	0	4
pumpata	pumppasi	to pump	8.96	0.40	0	4
kipata	kippassi	to tip	2.32	0.21	0	2
keilata	keilasi	to bowl	5.06	1.88	0	3
tankata	tankkasi	to fill up with petrol	5.49	0.31	0	2
kampata	kamppasi	to trip someone over	0.35	0.06	0	2
tiskata	tiskasi	to do dishes	1.57	0.04	0	2
surrata	surrasi	to buzz	0.78	0.08	0	3
lisätä	lisäsi	to add	441.11	32.07	0	0
törmätä	törmäsi	to crash into	54.82	18.50	0	0
ohjata	ohjasi	to steer	188.10	14.53	0	0
korjata	korjasi	to fix	120.76	7.88	7.22	0
napata	nappasi	to catch	35.75	16.19	14.44	0
maalata	maalasi	to paint	51.16	5.81	18.05	0
arvata	arvasi	to guess	36.83	0.91	7.22	0
kurkata	kurkkasi	to peek	0.66	0.02	10.83	0
hypätä	hyppäsi	to jump	55.34	13.34	64.98	1
kiusata	kiusasi	to tease	24.92	2.15	0	0
leimata	leimasi	to stamp	36.56	4.26	0	0
murskata	murskasi	to crush	14.33	2.21	0	0
paikata	paikkasi	to patch	18.66	1.72	0	0
hölkätä	hölkkäsi	to jog	1.61	0.21	0	0
tuhlata	tuhlasi	to spend	10.87	0.74	0	0
kahlata	kahlasi	to paddle (e.g., child in a pool)	3.90	0.34	0	0
kärrätä	kärräsi	to push a wheel barrow	2.33	0.18	0	0
filmata	filmasi	to film	4.22	0.28	0	0
vispata	vispasi	to whisk	1.16	0.26	0	0
putsata	putsasi	to clean	4.44	0.40	0	0

TABLE A2
Semi-productive verbs (*i*-suffix), their base and surface frequencies and adjusted phonological neighbourhood densities

<i>Infinitive form</i>	<i>Past tense form</i>	<i>Gloss</i>	<i>Base, freq/mil</i>	<i>Past tense surface, freq/mil</i>	<i>Past tense surface frequency, Pti/mil</i>	<i>Adjusted PND</i>
voittaa	voitti	to win	478.36	216.85	21.66	2
näyttää	näytti	to show	567.10	77.34	0	2
heittää	heitti	to throw	131.59	31.47	86.64	2
soittaa	soitti	to play an instrument	192.77	27.61	104.69	2
toistaa	toisti	to repeat	36.63	12.38	7.22	2
pysäyttää	pysäytti	to stop	49.31	8.54	0	2
poistaa	poisti	to erase	119.15	6.24	7.22	2
tiputtaa	tiputti	to drop	4.51	1.01	36.1	2
tupsahtaa	tupsahti	to appear	3.33	0.97	14.44	4
vilkuttaa	vilkutti	to wave	2.56	0.58	14.44	2
liittää	liitti	to attach	63.99	3.22	0	3
täräyttää	täräytti	to bang	5.05	3.11	0	4
mököttää	mökötti	to sulk	0.39	0.02	0	6
käkättää	käkätti	to cackle	0.19	0.02	0	3
kilkuttaa	kilkutti	to tinkle (e.g., instrument)	0.16	0.02	0	2
rimputtaa	rimputti	to ring (e.g., doorbell) continuously	0.05	0.02	0	2
hytkyttää	hytkytti	to shake	0.05	0.01	0	3
köröttää	körötti	to trundle along (in an old car)	0.14	0.01	0	3
lorottaa	lorotti	to splash	0.39	0.01	0	2
vollottaa	vollotti	to howl	0.15	0.01	0	2
esittää	esitti	to act	673.63	89.01	21.66	0
yllättää	yllätti	to surprise	158.23	28.72	14.44	0
herättää	herätti	to wake someone up	132.19	26.26	14.44	0
odottaa	odotti	to wait	566.62	16.46	18.05	0
syöttää	syötti	to feed	27.01	10.31	7.22	0
lämmittää	lämmitti	to heat up	28.93	3.36	14.44	0
pamahtaa	pamahti	to bang	2.64	1.25	25.27	0
istahtaa	istahti	to sit down (casually)	6.03	1.06	14.44	0
värittää	väritti	to colour	8.33	0.85	14.44	0
hypähtää	hypähti	to spring	1.51	0.59	14.44	0
kannustaa	kannusti	to cheer	49.55	4.60	0	0
peruuttaa	peruutti	to reverse	25.44	4.57	0	0
selostaa	selosti	to commentate	16.45	4.56	0	0
venyttää	venytti	to stretch	11.50	2.97	0	0
tykittää	tykitti	to bomb	4.69	2.61	0	0
jäädyyttää	jäädyytti	to freeze	14.24	2.24	0	0
virnistää	virnisti	to grin	4.51	0.90	0	0
kalastaa	kalasti	to fish	15.60	0.68	0	0
pölyyttää	pölyytti	to dust	1.48	0.65	0	0
lävistää	lävisti	to pierce	2.41	0.58	0	0

TABLE B
Nonproductive (i.e., qualitative stem change) verbs, their base and surface frequencies
and adjusted phonological neighbourhood densities

<i>Infinitive form</i>	<i>Past tense form</i>	<i>Gloss</i>	<i>Past tense allomorph</i>	<i>Base, freq/mil</i>	<i>Past tense surface, freq/mil</i>	<i>Past tense surface frequency, Piia/mil</i>	<i>Adjusted PND</i>
annella	anteli	to give	i	0.08	0.00	0	0
huudella	huuteli	to shout	i	5.21	0.72	14.44	1
jaella	jakeli	to hand out	i	5.94	1.31	0	0
kierrellä	kierteli	to wander/circle	i	16.24	2.72	0	0
kuunnella	kuunteli	to listen	i	107.67	6.60	0	0
madella	mateli	to crawl	i	1.98	0.73	0	2
työnnellä	työnteli	to push	i	0.79	0.12	0	0
vaihdella	vaihteli	to exchange	i	98.32	5.52	0	0
jahdata	jahtasi	to chase	si	11.70	0.78	0	2
karata	karkasi	to run away	si	42.73	16.84	0	0
levätä	lepäsi	to rest	si	26.38	1.49	0	0
liata	likasi	to dirt/soil	si	2.91	0.09	0	0
luvata	lupasi	to promise	si	231.60	52.31	0	0
maata	makasi	to lie down	si	22.62	2.71	0	2
mullata	multasi	to soil	si	0.93	0.00	0	1
pelätä	pelkäsi	to be scared of	si	173.00	7.52	0	0

TABLE C
Novel verbs and their phonological neighbourhood sizes

<i>Infinitive form</i>	<i>Past tense form</i>	<i>Past tense allomorph</i>	<i>Base, freq/mil</i>	<i>Past tense surface, freq/mil</i>	<i>Adjusted PND</i>
keinittää	keinitti	i	0	0	0
kiisittää	kiisitti	i	0	0	0
kolvittaa	kolvitti	i	0	0	0
lasvittaa	lasvitti	i	0	0	0
märayttää	märaytti	i	0	0	5
näkistää	näkisti	i	0	0	0
novauttaa	novautti	i	0	0	0
pöröttää	pörötti	i	0	0	4
pupsahtaa	pupsahti	i	0	0	5
sytkyttää	sytkytti	i	0	0	4
toittaa	toitti	i	0	0	3
vököttää	vökötti	i	0	0	7
hyölätä	hyöläsi	si	0	0	0
kalskata	kalskasi	si	0	0	0
kastata	kastasi	si	0	0	3
kennata	kennasi	si	0	0	0
kumpata	kumppasi	si	0	0	5
liskata	liskasi	si	0	0	3
netlata	netlasi	si	0	0	0
riehätä	riehäsi	si	0	0	0
toulata	toulasi	si	0	0	0
turrata	turrasi	si	0	0	3
veilata	veilasi	si	0	0	4
velata	velasi	si	0	0	4