COGNITIVE SCIENCE
A Multidisciplinary Journal

Cognitive Science 44 (2020) e12879

ISSN: 1551-6709 online
DOI: 10.1111/cogs.12879

Production of Inflected Novel Words in Older Adults With and Without Dementia

Alexandre Nikolaev,[a,b] Eve Higby,[c,d] JungMoon Hyun,[e] Minna Lehtonen,[f] Sameer Ashaie,[g,h] Merja Hallikainen,[i,j] Tuomo Hänninen,[i] Hilkka Soininen[j]

[a]*Helsinki Collegium for Advanced Studies, University of Helsinki*
[b]*School of Languages and Cultures, University of Sheffield*
[c]*Speech, Language, and Hearing Sciences, California State University, East Bay*
[d]*Psychology, University of California, Riverside*
[e]*Speech-Language Pathology & Audiology, Hunter College, The City University of New York*
[f]*Center for Multilingualism in Society Across the Lifespan, Department of Linguistics and Scandinavian Studies, University of Oslo*
[g]*Shirley Ryan AbilityLab*
[h]*Feinberg School of Medicine, Northwestern University*
[i]*Kuopio University Hospital*
[j]*Institute of Clinical Medicine, Neurology, University of Eastern Finland*

Received 23 November 2019; received in revised form 13 June 2020; accepted 17 June 2020

Abstract

While cognitive changes in aging and neurodegenerative disease have been widely studied, language changes in these populations are less well understood. Inflecting novel words in a language with complex inflectional paradigms provides a good opportunity to observe how language processes change in normal and abnormal aging. Studies of language acquisition suggest that children inflect novel words based on their phonological similarity to real words they already know. It is unclear whether speakers continue to use the same strategy when encountering novel words throughout the lifespan or whether adult speakers apply symbolic rules. We administered a simple speech elicitation task involving Finnish-conforming pseudo-words and real Finnish words to healthy older adults, individuals with mild cognitive impairment, and individuals with Alzheimer's disease (AD) to investigate inflectional choices in these groups and how linguistic variables and disease severity predict inflection patterns. Phonological resemblance of novel words to both a regular and an irregular inflectional type, as well as

Correspondence should be sent to Alexandre Nikolaev, Helsinki Collegium for Advanced Studies, University of Helsinki, PO Box 4 (Fabianinkatu 24), FIN 00014 Helsinki, Finland. E-mail: alexandre.nikolaev@helsinki.fi

bigram frequency of the novel words, significantly influenced participants' inflectional choices for novel words among the healthy elderly group and people with AD. The results support theories of inflection by phonological analogy (single-route models) and contradict theories advocating for formal symbolic rules (dual-route models).

Keywords: Phonological analogy; Inflectional morphology; Single-route models; Dual-route models; Alzheimer's disease; Mild cognitive impairment; Aging; Language

1. Introduction

When novel words, such as loan words, enter a language, they adapt to the new language, including adapting to a new inflectional system. For example, the English noun *joker* is borrowed into Finnish as *jokeri* by adding an epenthetic vowel *i* which allows the novel word to enter an existing inflectional paradigm of Finnish. The plural form of the Finnish noun *jokeri* receives the Finnish plural marker *-t*, resulting in the plural form of the word, *jokerit*, which eventually became the name of an ice hockey team from Helsinki. When the team joined the Russian KHL league in 2014, Russian speakers started to inflect the word *Jokerit* (Йокерит) by adding number and case suffixes, conforming to the Russian inflectional paradigm of a masculine singular nominative form, even though the word is technically already pluralized in Finnish with the *-t* ending and has no gender category. Many languages have various inflectional options for these newcomers. However, typically only a few of the options are productive, meaning that they are used to inflect new words that are added to the language (for ontogenesis of the English language, see e.g., Lieberman, Michel, Jackson, Tang, & Nowak, 2007; for the relative productivity of one Finnish inflectional paradigm over others in early L1 acquisition, see e.g., Niemi & Niemi, 1987).

Productive inflectional options tend to be considered *regular* (e.g., the addition of *-s* for English plurals, *leg*: *legs*) as opposed to the so-called *irregular* forms (e.g., *foot*: *feet*), which are not productive inflectional patterns in English because of various phonological changes that have taken place in diachrony. The relation between productivity of a certain inflectional pattern and the number of novel words following this pattern is accumulative; greater productivity leads to a higher number of novel words adopting that inflectional paradigm, whereas lower productivity means that the paradigm incorporates fewer novel words or no novel words at all.

In the present study, we aim to investigate how language users choose to inflect unfamiliar (novel) words and whether this approach changes with aging and neurocognitive disorders. For adults, inflecting novel words is just a small fraction of everyday language use. Keuleers, Stevens, Mandera, and Brysbaert (2015) found that although adults' vocabulary increases with age, the rate of growth decreases with age. The authors explain the slowing of vocabulary growth as being a result of Herdan's law (the more words one knows, the lower one's probability of encountering an unlearned word in the environment; Herdan, 1960). Following Herdan's law, for children acquiring their first language, plenty of words that an adult would consider familiar are novel to them. Thus, the vast majority of studies concentrating on inflecting unfamiliar words are developmental studies. Nevertheless, the cognitive mechanisms used for inflecting unfamiliar words during language acquisition are related to the cognitive mechanisms used later in life for inflecting novel words because the former eventually evolves into the latter.

There are two major theories explaining the cognitive mechanisms involved in novel word inflection: one theory advocating for phonological analogy (single-route models) and another advocating for formal symbolic rules (dual-route models). Four studies have examined these cognitive mechanisms in preschool-age children who speak an inflectionally rich and highly complex language, Finnish (Engelmann et al., 2019; Granlund et al., 2019; Kirjavainen, Nikolaev, & Kidd, 2012; Räsänen, Ambridge, & Pine, 2016). These studies suggest that a theory assuming storage and phonological analogy explains the results better than a theory assuming formal symbolic rules. However, to the best of our knowledge, no study has examined predictions of these two theories for how adult Finnish speakers inflect novel words. If the results from adults support storage and phonological analogy over formal symbolic rules, this would provide evidence that speakers use the same cognitive mechanisms when dealing with novel words during language acquisition and language use later in life. However, if the results support formal symbolic rules over storage and phonological analogy, this would suggest that the mechanisms used during language acquisition are no longer used in later life.

1.1. Storage and phonological analogy versus formal symbolic rules

The current approaches explaining how morphological rules are applied to novel word forms—one assuming storage and phonological analogy and the other assuming formal symbolic rules—are in principle reactions to the Bloomfieldian model (Bloomfield, 1933). In the Bloomfieldian model, inflected forms are considered to be derived from their "dictionary forms" (e.g., Chomsky & Halle, 1968) either by a simple rule, in the case of regular words, or by rule-based descriptions in the case of irregular words (see more detailed discussion regarding this topic in Baayen, 2007, and in Granlund et al., 2019). The two approaches stem from two concurrent theoretical schools, constructivism and generative grammar, and they disagree on what types of cognitive mechanisms are involved in processing regularly versus irregularly inflected words.

According to dual-route models (e.g., Marcus et al., 1992; Pinker, 1991; Prasada & Pinker, 1993), language users inflect words (e.g., *sneak*) either by retrieving a whole inflected word form from an associative lexical memory, if there is such a form (e.g., *snuck*), or by applying context-free symbolic rules (e.g., adding the default past-tense suffix *-ed*: *sneaked*). By contrast, single-route models (such as schema, Bybee & Moder, 1983; Langacker, 2000, or neuronal network models, also known as connectionist or deep learning models, Rumelhart, & McClelland, 1986; Plunkett & Marchman, 1993) suggest that we use the same cognitive mechanism, namely a single associative process, for both regular (*sneaked*) and irregular (*snuck*) word forms. Thus, both the single-route and dual-route approaches agree that irregularly inflected words (e.g., *taught*, *ran*, *children*) are stored in the mental lexicon as whole forms. Their disagreement primarily involves the mechanism used to inflect regular words.

In the case of the inflection of novel words, the dual-route models assume the same mechanism as for regular words, namely context-free symbolic rules: Novel words will be inflected as if they are regular words. However, an exception to this rule is applied if a novel word resembles an existing irregular word phonologically, whereby the novel word might be inflected irregularly via analogy. By contrast, the single-route models assume that all novel words are inflected via analogy: In order to be inflected irregularly, a novel word should resemble an irregular word phonologically, whereas in order to be inflected regularly, a novel word should resemble a regular word (e.g., Blything, Ambridge, & Lieven, 2018). Therefore, a crucial difference between the two models is the importance of phonological similarity between novel and existing words.

The holistic representation of an inflected pseudo-word simply does not exist in the mental lexicon. Thus, when a speaker is asked to inflect a pseudo-word (i.e., a novel word), the only available route is (de)composition, and he or she has to rely on a different set of cues than when inflecting existing words.

1.2. Influence of age or cognitive decline

Given that many aspects of the language and cognitive systems change in aging, it is not clear whether the application of inflectional morphology in language production changes in aging. It is not a self-evident fact that any theory suited to describe a mechanism of inflection used in language acquisition is automatically suited to describe a mechanism of inflection used by older adults. In fact, Räsänen et al. (2016) found a decreasing reliance on phonological analogy with age, even within the age range 2;2–4;8 years (a similar finding is reported in Engelmann et al., 2019). They explain this finding by suggesting that learners' knowledge of the inflectional system becomes increasingly abstract with age. The authors also propose that the importance of phonological neighborhood density may decline in adults. If a 5-year-old child relies less on phonological analogy than a 3-year-old, then we might expect that an adult relies even less on phonological analogy when inflecting unfamiliar words (cf. to an extreme exemplar account, Ambridge, 2019, where the author argues that children simply store exemplars and develop the ability to analogize across them on the fly, so that later in life, as adults, they rely on this ability only).

In contrast to the lack of research on inflectional patterns in health aging, some attention has been given to the influence of dementia on the regular vs. irregular inflection of novel words (Colombo, Fonti, & Stracciari, 2009; Walenski, Sosta, Cappa, & Ullman, 2009). A neurolinguistic extension of the dual-route model proposed by Ullman (2001, 2004, 2016)—the declarative/procedural (DP) model—makes clear predictions about what type of memory is involved in regular and irregular inflection and, thus, what type of impairments should manifest in dementia based on the patterns of brain atrophy found in this disease. According to this model, irregular word forms like *children* are learned through, stored in, and retrieved from declarative memory. By contrast, regular words are inflected using either declarative or procedural memory. Declarative memory contains knowledge that is accessed explicitly and is stored in the hippocampus and other medial temporal lobe structures while procedural memory contains implicit knowledge/skills and is considered to relate to the frontal/basal ganglia circuits of the brain. This model predicts that people with Alzheimer's disease (AD), who show declines in function in the hippocampal circuit, would show difficulties in the processing and retrieval of irregular word forms and would be less likely to produce irregular forms for novel words.

Single-route models, on the other hand, predict that the severity of AD should have no disproportionate effect on the way novel words are inflected. Instead of explaining production patterns according to the deterioration of explicit memory (although, depending on the stage of AD, semantic memory might be better preserved than episodic memory, see e.g., Albert, 2011; Nebes, 1989) versus preservation of implicit memory in AD, single-route models attribute choices in inflectional patterns for novel words to deterioration of patients' attention (Cortese, Balota, Sergent-Marshall, Buckner, & Gold, 2006) or working memory involved in the manipulation of morpho-phonological segments (Colombo et al., 2009). According to Cortese et al. (2006), attention plays a crucial role in selection of one inflectional form and inhibition of other possible candidates (e.g., *spit*, *spat*, *spitted* as past tense forms of the verb *spit*). The authors found that individuals with AD do not exhibit an increase in the regularity effect in comparison to healthy controls, but rather their inflection of English verbs in past tense depended on how many phonological neighbors the verbs had in regular or irregular inflectional classes. Colombo et al. (2009) studied inflection of Italian verbs and pseudo-verbs by individuals with AD. Participants with AD produced more errors while inflecting pseudo-words than healthy controls. Since inflecting pseudo-words requires manipulation of morpho-phonological segments, which in turn may require an efficient phonological working memory system, deterioration of such a system due to AD explains, according to Colombo et al., errors produced by individuals with AD.

The present study aims to examine how elderly people inflect novel words (pseudo-words) and whether inflection is influenced by cognitive decline due to AD or mild cognitive impairment (MCI). Considering that people with AD or MCI show a deficit in various cognitive domains, especially in memory for AD, these groups allow us to examine how the cognitive mechanisms used to inflect novel words (analogy vs. symbolic rules) in a morphologically complex language are related to declarative and procedural memory or to phonological working memory. In the present study, participants' strategies for inflecting pseudo-words were investigated using a simple speech elicitation task (Berko, 1958). A recent study by Nikolaev et al. (2019) investigated morphological processing for participants with MCI, AD, and neurologically healthy young and older adults using a visual word recognition experiment. The authors found an unexpected pattern for the group of individuals with MCI in terms of the influence of morphological complexity on language comprehension. Somewhat surprisingly, individuals with MCI were the only group that was not influenced by the morphological complexity of words: Their reaction times to words with more complex stem allomorphy did not differ from reaction times to words with less complex stem allomorphy, although overall their reaction times were on average faster than those of the AD group. Thus, the current study aims to investigate the production of inflected novel words among the three older-adult groups and to examine whether differences emerge for the MCI group compared to the neurologically healthy participants and those with AD.

1.3. Inflectional system of the Finnish language

The Finnish language is a good source to compare the single- and the dual-route models because of its morphological complexity. However, predictions of the two approaches can be tested only if we are able to measure phonological similarity of novel words to existing words (regular and irregular). We discuss the measure of phonological similarity we chose in the next section.

While pluralization of English regular nouns is embodied in a voiceless or voiced fricative suffix (e.g., *kid*: *kids*), pluralization of irregular nouns range from vocalic alternation (*tooth*: *teeth*) or unproductive suffixation (*ox*: *oxen*) to a combination of vocalic alternation and unproductive suffixation (*child*: *children*) or invariance (*fish*: *fish*) (for analysis of different inflectional classes of English verbs, see e.g., Bybee & Moder, 1983). However, the complexity of a word's irregular inflectional paradigm in English and in other Indo-European languages is typically ignored in the traditional dichotomy of regular versus irregular inflection.

What makes Finnish a highly complex inflectional language is that speakers often have to choose among both stem allomorphs and suffix allomorphs (see Table 1; nouns following the same inflectional paradigm, e.g., *lasi* "glass," constitute an inflectional class). In fact, in languages like Finnish, productivity of a certain inflectional class is not a matter of its regularity, but rather depends on the complexity of the inflectional paradigm. The complexity of different inflectional paradigms can be viewed as a continuum from the least complex to the most complex paradigm (see gradient properties of, e.g., Russian inflectional morphology, Gor & Jackson, 2013, or Italian inflectional morphology, Colombo et al., 2009, as opposed to the categorical dichotomy of English).

The complexity of an inflectional paradigm contributes to how (un)predictable an inflected form (e.g., *lasia* vs. *vettä*) is from its nominative singular form (*lasi* vs. *vesi*). Some recent studies have operationalized inflectional complexity in terms of inflectional entropy (Moscoso del Prado Martín et al., 2004), inflectional paradigm size (Lõo, Järvikivi, & Baayen, 2018; Lõo, Järvikivi, Tomaschek, Tucker, & Baayen, 2018), or the number of stem allomorphs in the inflectional paradigm (Nikolaev et al., 2014, 2019; Nikolaev, Lehtonen, Higby, Hyun, & Ashaie, 2018).

Table 1 presents three concurrent inflectional paradigms that cover all *i*-final Finnish nouns exemplified here by the words *lasi* "glass," *savi* "clay," and *vesi* "water." The *lasi* paradigm has no stem changes in the singular word form and only one stem change for all plural word forms. This is the least complex inflectional paradigm, the one that might be considered "regular," and it is also the most productive of the three inflectional paradigms, meaning it is often adopted for novel words. Two other noun types, *savi* and *vesi*, show stem changes in several singular word forms. These changes (i.e., stem allomorphs)

Table 1
A number and case matrix of three Finnish *i*-final noun paradigms

	Singular	Plural
Lexical entry: *lasi* glass		
nominative	lasi	lasi–t
genitive	lasi–n	lasi–en
partitive	lasi–a	lase–ja
essive	lasi–na	lase–i–na
translative	lasi–ksi	lase–i–ksi
inessive	lasi–ssa	lase–i–ssa
elative	lasi–sta	lase–i–sta
illative	lasi–in	lase–i–hin
adessive	lasi–lla	lase–i–lla
ablative	lasi–lta	lase–i–lta
allative	lasi–lle	lase–i–lle
abessive	lasi–tta	lase–i–tta
comitative		lase–i–ne–(poss)
instructive		lase–i–n
Lexical entry: *savi* clay		
nominative	savi	save–t
genitive	save–n	savi–en
partitive	save–a	savi–a
essive	save–na	savi–na
translative	save–ksi	savi–ksi
inessive	save–ssa	savi–ssa
elative	save–sta	savi–sta
illative	save–en	savi–in
adessive	save–lla	savi–lla
ablative	save–lta	savi–lta
allative	save–lle	savi–lle
abessive	save–tta	savi–tta
comitative		savi–ne–(poss)
instructive		savi–n
Lexical entry: *vesi* water		
nominative	vesi	vede–t
genitive	vede–n	vesi–en
partitive	vet–tä	vesi–ä
essive	vete–nä	vesi–nä
translative	vede–ksi	vesi–ksi
inessive	vede–ssä	vesi–ssä
elative	vede–stä	vesi–stä
illative	vete–en	vesi–in
adessive	vede–llä	vesi–llä
ablative	vede–ltä	vesi–ltä
allative	vede–lle	vesi–lle
abessive	vede–ttä	vesi–ttä
comitative		vesi–ne–(poss)
instructive		vesi–n

have to be memorized by language users since there are no explicit phonological cues in the words *savi* and *vesi* that can be used to predict these allomorphs. Hence, these two word types might be considered "irregular." However, the current study aims to disentangle graded morphological complexity from dichotomous (ir)regularity.

Even though *savi* and *vesi* are both irregular in Finnish, *vesi* has a more complex inflectional paradigm than *savi* due to the higher number of different stem allomorphs in its paradigm (four in *vesi* compared to two in *savi*).

1.4. Measures of phonological similarity

If we assume that language users associate novel words with existing words based on the phonological similarity between them, then a measure of this phonological similarity should be able to predict inflectional patterns that language users apply to novel words. There are several ways to measure phonological similarity of novel words to existing regular and irregular words in Finnish. Engelmann et al. (2019) used a class size measure to denote phonological similarity. In other words, they calculated how many words share the same inflectional paradigm. The authors refer to this measure as "phonological neighborhood density." Following Engelmann et al. (2019), the class size of the three word types we used in the present study (Table 1) would be 4,557 for *lasi*, 113 for *savi*, and 95 for *vesi* (Basic Dictionary of Finnish, 1990–1994). However, class size is more a consequence of the productivity of this inflectional class than a measure of the number of phonological neighbors.

To better measure the phonological distance between novel words and existing words in the language, we chose the *Optimal String Alignment distance* (OSA; van der Loo, 2014). The OSA is similar to the *Levenshtein distance* (LD; Levenshtein, 1966), which is computed by counting the number of insertions, deletions, and substitutions necessary to turn one string into another. However, the OSA also allows for transpositions of adjacent characters. The OSA is also referred to as the *restricted Damerau–Levenshtein distance* (van der Loo, 2014; Lowrance & Wagner, 1975).

A set of Finnish pseudo-words were created according to the morphophonological rules of Finnish; these acted as novel words in the study. We calculated the OSA between each pseudo-word used in the present study and each real word from types *lasi*, *savi*, and *vesi* (Basic Dictionary of Finnish, 1990–1994). The OSA was calculated using graphemes. However, since Finnish orthography–phonology mapping is isomorphic, we use this measure as an index of phonological resemblance.

2. Method

2.1. Participants

We recruited individuals with MCI or AD when they visited the Neurological Clinic at Kuopio University Hospital and healthy older adults (who did not show obvious neurological, psychiatric, cognitive, or functional changes in daily life) through a research project at the Brain Research Unit of the University of Eastern Finland. Individuals with AD were selected by NINCDS-ADRDA Alzheimer's criteria (McKhann et al., 2011) for probable AD or prodromal AD (Dubois et al., 2007), while individuals with MCI were selected by the criteria set by the International Working Group on MCI (Albert et al., 2011; Winblad et al., 2004). In all, 63 elderly adults took part in this study: 17 cognitively healthy controls (HC, aged 55–79, mean 65.8, *SD* 6.6, 8 females), 22 individuals with AD (age 56–83, mean 72.7, *SD* 7.6, 12 females), and 24 individuals with MCI (age 58–81, mean 72.4, *SD* 6.5, 11 females). The same participants took part in a written word recognition task described in Nikolaev et al. (2019). All were native Finnish speakers, and none of them had learned another language before starting school. Before the session, each participant gave written informed consent. The research was approved by the local ethical research committee.

Other possible pathologies that could account for patients' symptoms were ruled out via an MRI assessment, cerebrospinal fluid (CSF) analysis, electrocardiography, screening for hypertension and depression, and blood tests. Subjects were excluded from participation if they had other causes of dementia or if they had any obvious brain, systemic, or psychiatric disorders that could potentially affect cognitive functions, such as a stroke, severe depression, or endocrine disorders. Experienced neurologists diagnosed individual patients and determined the person's disease status.

We used the Sum of Boxes score from the Clinical Dementia Rating Scale (CDR-SOB; Hughes, Berg, Danziger, Coben, & Martin, 1982) as a global measure of cognitive assessment. The CDR-SOB reflects the sum of six domains of the CDR (memory, orientation, judgment and problem solving, community affairs, home and hobbies, and personal care) and thus disease severity (Balsis, Benge, Lowe, Geraci, & Doody, 2015; Ito & Hutmacher, 2014; O'Bryant et al., 2010). Scores from the CDR-SOB revealed statistically significant differences between the AD and control groups (multiple comparisons test after Kruskal–Wallis: observed difference = 39.8, critical difference = 13.9) and between the AD and MCI groups (obs. dif. = 17.7, crit. dif. = 12.8), as well as between the MCI and control groups (obs. dif. = 22.1, crit. dif. = 13.6).

2.2. *Task*

All the participants were tested by the same one experimenter, ensuring consistency across participants. The participants were given oral instructions to orally finish a sentence begun by the experimenter. The sentence frame was always the same except for the name of the subject and the target word in each sentence (underlined in the following examples). An example sentence with a real word is *Johannalle* <u>*hirsi*</u> *on tärkeää, mutta hän ei saanut yhtään …* ("For Johanna a <u>log</u> is important, but she hasn't got any …"), which should elicit singular partitive form of the noun given in the sentence (in this case *hirttä,* the singular partitive of *hirsi* "log"). An example sentence with a pseudo-noun is *Niklakselle* <u>*tuusi*</u> *on tärkeää, mutta hän ei saanut yhtään …* ("For Nicholas a <u>tuusi</u> is important, but he hasn't got any …"). The experiment started with four practice trials using real nouns that belonged to different inflectional types than the test items. The duration of the experiment was approximately 25 min. The interstimulus interval (time interval between the offset of the last word produced by the participant and the onset of the first word produced by the experimenter) ranged from 1 second to a few seconds. If during the experiment the participant made a comment or asked a question, the experimenter tried to provide the participant with an appropriate response (e.g., saying *yes*, *okay*, *good*, or *sure*) and then return to the experiment procedure as quickly as possible in order to keep the participant's attention on the experiment. If the participant produced more than one inflectional variant for a given stimulus, the participant was not asked to specify which one was final (the most complex response was used for coding). Participants in all three groups (HC, MCI, and AD) were tested using the same procedure. The testing was performed in the Neurological Department of the University Hospital of Kuopio or in the Brain Research Unit of the University of Eastern Finland. All experimental sessions were audio-recorded and transcribed for later scoring.

2.3. Materials

We built three sets of 33 *i*-final pseudo-words by randomly picking first syllables from all the words of a given word type (*lasi* "glass," *savi* "clay," and *vesi* "water," see Table 1 and Table S1) and combining them with randomly chosen second syllables from the same word type. We then removed any combinations that happened to produce real words and any pseudo-words that violated the phonotactics of the Finnish language. In addition to the 99 pseudo-words, 99 real Finnish *i*-final monomorphemic nouns were selected to create three sets of 33 nouns from the same inflectional types (*lasi*, *savi*, and *vesi*, Table 1). All test items (99 pseudo-words and 99 real words) had two syllables. In order to make sure that pseudo-words sounded like potential words of each word type, we matched the bigram frequency of the pseudo-words[1] with that of the real words used in the experiment. Mean bigram frequency of the pseudo-words was 361 (*SD* 222) and of real words, 369 (*SD* 204; two sample t test = 0.28, p = .78).

2.4. Data analysis

2.4.1. Phonological similarity

To determine phonological similarity, the average OSA between each of the 99 pseudo-words and all real, two-syllable *i*-final Finnish words (according to the Basic Dictionary of Finnish, 1990–1994) was calculated: 1,180 two-syllable *lasi*-type words,[2] 113 *savi*-type words, and 95 *vesi*-type words. Hence, each pseudo-word had three sets of numerical values: 1,180 OSAs between the pseudo-word and each of the *lasi*-type words, 113 OSAs for *savi*-type words, and 95 OSAs for *vesi*-type words. The OSA values for each word type were then averaged separately for each pseudo-word to determine its phonological overlap with each of these three inflectional classes. For example, the OSA-*lasi* of a given pseudo-word is the average OSA from this pseudo-word to all two-syllable *lasi*-type words in Finnish (Table S1 lists the average OSAs for each pseudo-word and word type). OSA averages for each word type were used as explanatory variables in the analysis.

2.4.2. Lexical variables

Other variables were included in the analysis that have been widely used in the psycholinguistic literature and that might influence pseudo-word inflection. Orthographic neighborhood density and Hamming distance of one (HD1; Coltheart, Davelaar, Jonasson, & Besner, 1977) were calculated using the Basic Dictionary of Finnish (1990–1994) by counting the number of words with the same length but differing only in the initial letter (neighborhood density) or in any single letter (HD1). Since Finnish orthography–phonology mapping is isomorphic, orthographic neighbors are equivalent to phonological neighbors. Bigram frequency, initial trigram frequency, and final trigram frequency (i.e., the average number of times that all combinations of two or three subsequent letters occur in the corpus) were obtained for real words as well as for pseudo-words from the Turun Sanomat Corpus (22.7 million word tokens) using a computerized search program (Laine & Virtanen, 1999). All pseudo-words and their values on each of these variables are shown in Table S1.

2.4.3. Coding of inflected forms

All pseudo-words inflected according to the *lasi*-type (*lasi*:*lasia*), which is the regular type, were coded as 1, all pseudo-words inflected with the *savi*-type (*savi*:*savea*), an irregular type with moderate complexity, were coded as 2, and all pseudo-words inflected with the *vesi*-type (*vesi*:*vettä*), an irregular type with a high degree of complexity, were coded as 3. However, the numbers (1, 2, and 3) are not categorical: They correspond to the generalized LD between the given pseudo-word (e.g., *tuusi*) and the inflected pseudo-word produced by the participant (e.g., *tuusia*, *tuusea*, or *tuutta*). For example, one insertion (and no deletion or substitution) is needed to turn *lasi* to *lasia*, whereas one insertion and one substitution are needed to turn *savi* into *savea,* and two substitutions and one insertion are needed to turn *vesi* into *vettä*. Thus, the LD for *tuusi*:*tuusia* is 1, *tuusi*:*tuusea* is 2, and *tuusi*: *tuutta* is 3; higher LD values indicate more changes involved in inflecting the given word. If participants gave more than one response for a given test item, the most complex response was recorded. If the participant seemed to have misheard a given noun (e.g., substituted a pseudo-word with a real word), the response was excluded from the analysis. We obtained inter-coder reliability measurements on audio recordings of eight participants randomly chosen from the MCI group. The intercoder reliability coefficient was 0.943.

2.4.4. Analytical approach

Before analysis, we removed omissions (trials on which participants did not answer, coded as NA in Table 3) and responses elicited by mishearing the given word. Data from one participant with AD and two participants with MCI were not analyzed due to technical problems with the audio recordings. Thus, we report the data from 60 participants.

We analyzed the data using a cumulative link mixed model (Christensen, 2019). LD for inflected pseudo-words (1, 2, or 3) acquired from participants' productions served as the dependent variable. The models included subject, item, and trial as random-effect factors. We also added by-participant random slopes for significant predictors to check whether participants vary in their sensitivity to predictors. Some fixed-effect variables with Zipfian distributions (e.g., bigram frequency) were logarithmically transformed. Predictors and terms of interaction were entered into the model one at a time. After each step, the *anova* function was used to check if adding/dropping the predictor significantly influenced the predictive power of the new model. Participants' individual characteristics may also influence inflection of pseudo-words. For example, Nikolaev et al. (2019) found that more years of formal education had a positive effect on word recognition speed for healthy older adults, but not for people with AD. Therefore, we added years of education (HC, mean 13.7, *SD* 3.69; MCI, mean 10.42, *SD* 3.54; AD, mean 10.77, *SD* 4.17), as well as gender and age as participant-level explanatory variables.

3. Results

Since analysis of the inflection of real words is outside the scope of the current study, we present their aggregated results in Table 2 without further analysis.

Participants from all three groups inflected most pseudo-words according to the regular type *lasi*. Actual frequencies of each type with percentages for each group are presented in Table 3.

3.1. Elderly controls

Only four variables significantly explained the pseudo-word inflection patterns of the healthy elderly control (HC) group: OSA to *vesi*-type, OSA to *lasi*-type, bigram frequency, and the number of years of education (see Table 4). The negative estimate of OSA-*vesi* means that it correlated negatively with the complexity of inflection. In other words, the participants were more likely to produce a more complex, *vesi*-type inflection for pseudo-words that were—on average—more similar to real *vesi*-type words (i.e., those pseudo-words with smaller OSA-*vesi* values). OSA-*lasi*, on the other hand, had a positive estimate, which means that pseudo-words more similar to real *lasi*-type words tended to trigger a less complex, *lasi*-type inflection. Phonological similarity to the irregular but

Table 2
Percentages of real words inflected correctly by the three groups of participants; errors included responses with no inflection or an incorrect inflection, miscomprehension of the given word, and omissions

	HC	MCI	AD
lasi	93.6%	88.8%	87.3%
savi	89.5%	73%	73.2%
vesi	85.2%	69.7%	71.1%

Table 3
Total number of pseudo-words produced by all participants in each group (with relative percentages of each type of inflection among total acceptable inflections and with relative percentages of different types of errors among total errors)

	HC	MCI	AD
Correct inflection			
lasi-like forms	1,270 (84.5%)	1,576 (89.5%)	1,275 (81.8%)
savi-like forms	115 (7.7%)	99 (5.6%)	134 (8.6%)
vesi-like forms	118 (7.8%)	86 (4.9%)	149 (9.6%)
Total (ratio)	1,503 (89.3%)	1,761 (77.3%)	1,558 (78.7%)
Errors			
Other inflection	4 (2.2%)	0 (0.0%)	4 (0.9%)
Misheard	144 (80%)	391 (75.8%)	281 (66.6%)
Not inflected	31 (17.2%)	34 (6.6%)	39 (9.2%)
NA	1 (0.6%)	91 (17.6%)	98 (23.2%)
Total (ratio)	180 (10.7%)	516 (22.7%)	422 (21.3%)

Abbreviations: AD, Alzheimer's disease; HC, healthy controls; MCI, mild cognitive impairment.

less complex *savi*-type did not influence participants' inflectional choices. In addition to phonological similarity, bigram frequency correlated negatively with the complexity of inflected pseudo-words, reflecting the fact that words containing letter strings more commonly found in the language were more likely to be inflected regularly (according to *lasi*-type). Participants with more years of education tended to produce more complex inflections for pseudo-words than those with fewer years of education.

In sum, participants in the healthy elderly group tended to inflect *i*-final pseudo-words mostly according to the regular *lasi*-type (see Table 3), reflecting the fact that this type

Table 4
Estimate coefficients, standard errors, *z*- and *p*-values for the cumulative link mixed model fitted to the generalized Levenshtein distance between the given and inflected pseudo-words produced by elderly controls

Coefficients	Estimate	*SE*	*z*-value	*p*-value
OSA-*lasi*	3.412	1.402	2.434	.015
OSA-*vesi*	−2.227	0.744	−5.201	.003
log Bigram freq	−0.478	0.239	−1.998	.046
Education	0.187	0.077	2.424	.015

Random effects

Groups	Name	Variance	*SD*	Corr
Item	(Intercept)	0.871	0.933	
Subject	(Intercept)	1.834	1.354	
	Trial	7.48e−05	0.009	−0.648

Note Number of observations, 1,503; Items, 99; Subjects, 17.

of inflection prevails in real *i*-final Finnish words. However, phonological resemblance of pseudo-words to both a regular (*lasi*) and an irregular (*vesi*) inflectional type, as well as bigram frequency of the pseudo-words, significantly influenced participants' inflectional choices for pseudo-words (see Table 4).

3.2. Individuals with MCI

In contrast to the elderly control group, none of the phonological similarity variables predicted inflection patterns in the MCI group. This means that phonological similarity was not related to the complexity of inflected pseudo-words by the MCI participants. Education was not a significant predictor of the complexity of inflection in the MCI group. However, as in the elderly control group, bigram frequency partly explained the pattern of results for the MCI group, and its estimate had the same polarity as in the elderly control group.

The MCI group thus inflected most pseudo-words using the regular *lasi*-type (see Table 3). Phonological resemblance of pseudo-words to real words did not play a significant role. However, a more general phonological frequency measure—bigram frequency—was a significant predictor of the type of inflection: Those pseudo-words that were inflected via a complex inflectional type tended to have lower bigram frequency (Table 5).

3.3. Individuals with AD

In contrast to individuals with MCI, but in line with elderly controls, individuals with AD showed significant influence from the phonological similarity variables for *lasi* and *vesi*, showing that this group also relied on pseudo-words' similarity to real words in choosing how to inflect the pseudo-words. Like the other two groups, bigram frequency was a significant predictor of inflection patterns for individuals with AD. In addition, Score on the Clinical Dementia Rating (CDR-SOB) showed a significant interaction with OSA-*vesi*, meaning that the strength of the relationship between a pseudo-word's similarity to *vesi*-type words and the complexity of the inflection was reduced for individuals with more severe cognitive impairment compared to milder forms of cognitive

Table 5
Estimate coefficients, standard errors, *z*- and *p*-values for the cumulative link mixed model fitted to the generalized Levenshtein distance between the given and inflected pseudo-words produced by individuals with mild cognitive impairment

Coefficients	Estimate	*SE*	*z*-value	*p*-value
log Bigram freq	−0.769	0.23	−3.352	<.001

Random effects

Groups	Name	Variance	*SD*
Item	(Intercept)	1.03	1.015
Subject	(Intercept)	1.29	1.136

Note Number of observations, 1,761; Items, 99; Subjects, 23.

Table 6
Estimate coefficients, standard errors, *z*- and *p*-values for the cumulative link mixed model fitted to the generalized Levenshtein distance between the given and inflected pseudo-words produced by individuals with Alzheimer's disease

Coefficients	Estimate	*SE*	*z*-value	*p*-value
OSA-*lasi*	5.68	1.712	3.318	<.001
OSA-*vesi*	−5.002	0.962	−5.201	<.001
log Bigram freq	−0.665	0.23	−2.885	.004
CDR-SOB	0.001	1.122	0.001	.999
OSA-*lasi*: CDR-SOB	−0.776	0.406	−1.911	.056
OSA-*vesi*: CDR-SOB	0.813	0.253	3.216	.001

Random effects

Groups	Name	Variance	*SD*	Corr
Item	(Intercept)	0.785	0.886	
Subject	(Intercept)	1.56	1.249	
	Trial	2.74e−05	0.005	0.112

Note Number of observations, 1,558; Items, 99; Subjects, 20.

impairment. Like the MCI group, education did not significantly predict the complexity of inflection for participants with AD.

Individuals with AD demonstrated the same pattern of inflection as participants in the healthy elderly group. They inflected pseudo-words mostly according to the regular *lasi*-type (see Table 3); however, phonological resemblance of novel words to both a regular (*lasi*) and an irregular (*vesi*) inflectional type significantly influenced their inflectional choices for pseudo-words (see Table 6).

4. Discussion

Since pseudo-words have no lexical entry in the mental lexicon, there is no correct or incorrect way of inflecting them. However, speakers are not random in their choices about the inflectional patterns they assign new words, nor do they stick to only one paradigm and apply it to all pseudo-words. Instead, they appear to be sensitive to information contained in the pseudo-word, which must be orthographic/phonological. This information then leads speakers to retrieve an "appropriate" inflectional paradigm for the word (cf. Chuang et al., 2020, according to whom auditory pseudo-words are not semantically empty).

Since the lexicon is dynamic rather than static, with some novel words entering the language and other words dying or becoming archaic, the mental lexicon of any particular speaker is only a subset of the lexicon of the language. The cognitive mechanism used by an older adult to inflect novel words must have evolved from the mechanism used by a young child to inflect unfamiliar words. How this mechanism evolves is unclear.

According to single-route models, both children and older adults use the same cognitive mechanism to inflect regular and irregular words. The models predict that the phonological resemblance of pseudo-words to regular (*lasi*-type) or irregular (*vesi*-type) types plays a significant role in how speakers decide to inflect pseudo-words. According to dual-route models, both children and older adults apply context-free symbolic rules when retrieval of a whole inflected word form from an associative lexical memory is inefficient. The models predict that the phonological resemblance of pseudo-words to irregular types (*vesi*-type) might play a role in how speakers decide to inflect pseudo-words; however, the phonological resemblance of pseudo-words to the regular (*lasi*) type should play no role. Thus, the two theories differ in the extent to which each relies on phonological analogy.

In the present study, the phonological distance of pseudo-words to the most complex irregular type (*vesi*) was found to play a significant role for participants with AD and for elderly controls. The more similar a pseudo-word was to real *vesi*-type words, the more likely these participants were to inflect the pseudo-word using the inflectional paradigm of *vesi*-type words. This result was predicted by both the single-route and the dual-route models. However, the pseudo-word's average phonological distance to the regular type (*lasi*) also played a significant role: The more similar the pseudo-word was to the *lasi*-type, the more likely participants with AD and elderly controls were to inflect this pseudo-word according to the *lasi*-type. This result was only predicted by the single-route model. Based on our results, inflection of novel words by elderly adults with or without AD is better explained by a theory that places more weight on phonological analogy (the single-route model) than by a theory that underestimates analogy and instead proposes formal symbolic rules (the dual-route model). We note that some might disagree with the dichotomy of single- vs. dual-route models and suggest that both approaches might work in different tasks or different settings.

Interestingly, phonological resemblance of the pseudo-word to the most complex irregular type (*vesi*) had a significant influence on inflection choice while resemblance to the less complex irregular type (*savi*) did not. This result can help to disentangle the effects of regularity and complexity of an inflectional paradigm on inflectional choices. The complexity of an inflectional paradigm contributes to how (un)predictable an inflected form is from its nominative singular form and can be viewed as a continuum from the least complex to the most complex paradigm. The regularity of an inflectional paradigm also contributes to how (un)predictable an inflected form is from its "dictionary" base form. However, unlike complexity, regularity is traditionally viewed as two opposite poles rather than as a continuum. Regularity may be an important psycho-morphological distinction for languages like English but may fail to capture the wider variation of complexity in languages like Finnish or Russian (e.g., for Finnish, Nikolaev et al., 2014, 2018; for Russian, Gor & Jackson, 2013). As seen in our data, distinguishing between irregular forms with greater and lesser complexity (*vesi* vs. *savi*) was meaningful for the pattern of results. In the present study, elderly adults with or without AD inflected pseudo-words according to their phonological distance to either the most complex or the least complex word types, not according to their regularity. These results can be better explained by the concept of complexity rather than by regularity.

The results also reveal how language production changes in neurodegenerative disease. The severity of dementia in our clinical groups was measured with the CDR-SOB. In the MCI group, this measure had no significant effect on the inflection of pseudo-words. In the AD group, by contrast, participants with higher CDR-SOB scores (i.e., more advanced disease progression) were less sensitive to the phonological similarity of pseudo-words and real *vesi*-type words than participants with lower CDR-SOB scores. According to the DP model, the more severe the AD pathology, the less influence irregular words will have as exemplars for novel words that resemble them phonologically. Our results are in line with this prediction: Phonological analogy with the most complex irregular type *vesi* was indeed weakened for people with higher CDR-SOB scores (p = .001). The DP model predicts that phonological analogy with the regular type *lasi* should play no role for people with higher CDR-SOB scores. Indeed, the p-value of the term of interaction between OSA-*lasi* and CDR-SOB was not significant, but it approached significance (p = .056). Thus, alternatively, changes in the mechanism of novel word inflection associated with the disease's progression may be attributed to weakening of the phonological component of working memory (Collette, Van der Linden, Bechet, & Salmon, 1999; Colombo et al., 2009; Stopford, Thompson, Neary, Richardson, & Snowden, 2012) or attentional control (Cortese et al., 2006). Miscomprehensions of the given pseudo-word were excluded from the analyses. Miscomprehensions represented 8.6% of all responses in the HC group, 14.2% in the AD group, and 17.2% in the MCI group. Most of them were substitutions of real nouns phonologically similar to the target pseudo-words (i.e., lexicalizations). Individuals with AD in Colombo et al. (2009) also demonstrated an increase in this type of error in comparison to healthy controls. The authors explained this pattern as stemming from a decline in inhibitory control of competing lexical forms as a consequence of dementia.

Individuals with MCI showed a different pattern of results than healthy controls and individuals with AD. Phonological similarity to real words seemed to play no significant role in their decision of how to inflect pseudo-words. The same participants also took part in another experiment, a visual lexical decision task, described in Nikolaev et al. (2019). On the lexical decision task, the MCI group was the only one that showed no influence of the complexity of the inflectional paradigm (measured in the number of stem allomorphs) on recognition of real *lasi*-, *savi*-, and *vesi*-type words. Thus, it appears that in both language production and comprehension, the participants with MCI show weaker morphological effects than healthy older adults and AD patients. It is unclear why this group did not use phonological similarity to real words when choosing how to inflect the pseudo-words. We speculate two different reasons. The unique pattern demonstrated by this group may be due to the large variation in cognitive functions that were observed for this group. The diagnostic criteria for MCI in this study (Albert et al., 2011), the most commonly used criteria in research, encompass a broad range of people who display significant cognitive impairment in single or multiple cognitive domains. The impairment might be in memory, executive functions, attention, language, visuospatial skills, or any combination among them. Thus, individuals with MCI exhibited heterogeneous cognitive profiles. This large variation of cognitive characteristics might have resulted in unexpected results that differ from normal elderly or individuals with AD who are at the ends of the cognitive aging spectrum. Another characteristic of people with MCI, based on their diagnostic criteria, is that they should be able to maintain normal function in daily life. This means that they utilize relatively good compensation strategies to deal with their cognitive decline (see e.g., Lenzi et al., 2011; Yu, Li, Jiang, Broster, & Li, 2016), and this ability may result in the somewhat unique results in our study. The fact that individuals with MCI showed exceptional behavior in processing morphological complexity in both word recognition (Nikolaev et al., 2019) and word production (present study) warrants further investigation, which should be the focus of future studies.

Bigram frequency was a significant predictor of inflectional patterns in all three groups. High bigram frequency of a letter string means that the letter string is more commonly found in the language (or for languages with isomorphic orthography–phonology mappings, as in Finnish, this phonological sequence is more likely to be heard in speech). Pseudo-words with high bigram frequency correlated negatively with the complexity of their inflection. Pseudo-words with higher bigram (or in our case biphone) frequency are typically recognized faster as non-existing (and thus potentially novel) words (Hendrix & Sun, 2020). Ramscar, Hendrix, Shaoul, Milin, and Baayen (2014) explain this effect as a consequence of low activation of a large number of words as opposed to high activation of a small number of words for pseudo-words with lower bigram frequency. Therefore, one possible explanation for why pseudo-words with higher bigram frequency were inflected more regularly is that in general there are more regular words with highly frequent letter sequences.

More years of formal education has been found to correlate with preserved cognitive abilities in older age (e.g., Albert et al., 1995; Meara, Richards, & Cutler, 2008). An increase in level of educational attainment is associated with a reduction in incidence of dementia (e.g., Noble et al., 2017). There are debates about the relation between an individual's level of education and its influence on the slope of his or her cognitive decline once dementia is diagnosed. For example, Scarmeas, Albert, Manly, and Stern (2006) found that individuals with AD that have more educational experience exhibit faster cognitive decline. The effect of education on novel word production in older age has not been previously studied. We found a significant effect of years of education on the complexity of pseudo-words produced by the healthy elderly participants. Those with more years of education applied more morphophonological changes to pseudo-words, whereas those with fewer years of education preferred the most parsimonious strategy for inflecting unfamiliar words: Simply add a case suffix to the stem, avoiding any stem changes. Interestingly, we found no effect of education on the inflectional choices of people with MCI or AD. These results are in line with those reported in Nikolaev et al. (2019), in which more formal education had a positive effect on word recognition speed for healthy controls, but not for people with AD. The authors suggested that the beneficial effects of education might have disappeared in neurodegenerative disease.

5. Conclusion

The current study addressed the cognitive mechanisms involved in word inflection during language production. The results showed that older adults prefer to apply phonological analogy over formal symbolic rules when inflecting novel words, similar to what children do. These findings are in line with constructivist theories and single-route models of morphological production and diverge from the predictions of generative theories and dual-route models. AD appears to weaken the influence of phonological analogy, but only at more severe stages of the disease, which we attribute to problems with phonological working memory. MCI seems to weaken the influence of phonological analogy regardless of the severity of the disease, a rather surprising result which requires further investigation.

Acknowledgments

We thank all our participants and research assistants. We also thank Jamie Reilly, Davide Crepaldi, and an anonymous reviewer for their helpful comments and suggestions. This study is supported by VPH Dementia Research enabled by EU, grant agreement no. 601055.

For availability of data, contact the first author.

Notes

1. Due to the orthographic rules of Finnish, the relation between the bigram and biphone frequencies of Finnish words is isomorphic.
2. In Finnish, all *savi*- and *vesi*-type words have two syllables, whereas 1,180 out of 4,557 *lasi*-type words have two syllables.

References

Albert, M. S. (2011). Changes in cognition. *Neurobiology of Aging*, *32*, S58–S63.

Albert, M. S., DeKosky, S. T., Dickson, D., Dubois, B., Feldman, H. H., Fox, N. C., Gamst, A., Holtzman, D. M., Jagust, W. J., Petersen, R. C., Snyder, P. J., Carrillo, M. C., Thies, B., & Phelps, C. H. (2011). The diagnosis of mild cognitive impairment due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia: The Journal of the Alzheimer's Association*, *7*, 270–279.

Albert, M. S., Jones, K., Savage, C. R., Berkman, L., Seeman, T., Blazer, D., & Rowe, J. W. (1995). Predictors of cognitive change in older persons: MacArthur studies of successful aging. *Psychology and Aging*, *10*, 578–589.

Ambridge, B. (2019). Against stored abstractions: A radical exemplar model of language acquisition. *First Language*, 1–51. https://doi.org/10.1177/0142723719869731

Baayen, R. H. (2007). Storage and computation in the mental lexicon. In G. Jarema & G. Libben (Eds.), *The mental lexicon* (pp. 81–104). Oxford, UK: Elsevier.

Balsis, S., Benge, J. F., Lowe, D. A., Geraci, L., & Doody, R. S. (2015). How do scores on the ADAS-Cog, MMSE, and CDR-SOB correspond? *The Clinical Neuropsychologist*, *29*, 1002–1009.

Basic Dictionary of Finnish [Suomen kielen perussanakirja]. (1990–1994). Helsinki: Edita Oyj.

Berko, J. (1958). The child's learning of English morphology. *Word*, *14*, 150–177.

Bloomfield, L. (1933). *Language*. New York: Holt.

Blything, R. P., Ambridge, B., & Lieven, E. V. (2018). Children's acquisition of the English past-tense: Evidence for a single-route account from novel verb production data. *Cognitive Science*, *42*, 621–639.

Bybee, J. L., & Moder, C. L. (1983). Morphological classes as natural categories. *Language*, *59*, 25–55.

Chomsky, N., & Halle, M. (1968). *The sound pattern of English*. New York: Harper and Row.

Christensen, R. H. B. (2019). ordinal – Regression models for ordinal data. R package version 2019.4-25. Available at: http://www.cran.r-project.org/package=ordinal/

Chuang, Y. Y., Vollmer, M. L., Shafaei-Bajestan, E., Gahl, S., Hendrix, P., & Baayen, R. H. (2020). The processing of pseudoword form and meaning in production and comprehension: A computational modeling approach using linear discriminative learning. *PsyArXiv*. https://doi.org/10.31234/osf.io/byrux

Collette, F., Van der Linden, M., Bechet, S., & Salmon, E. (1999). Phonological loop and central executive functioning in Alzheimer's disease. *Neuropsychologia*, *37*(8), 905–918.

Colombo, L., Fonti, C., & Stracciari, A. (2009). Italian verb inflection in Alzheimer dementia. *Neuropsychologia*, *47*, 1069–1078.

Coltheart, M., Davelaar, E., Jonasson, J. T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornick (Ed.), *Attention and performance* (Vol. VI, pp. 535–556). Hillsdale, NJ: Erlbaum.

Cortese, M. J., Balota, D. A., Sergent-Marshall, S. D., Buckner, R. L., & Gold, B. T. (2006). Consistency and regularity in past-tense verb generation in healthy ageing, Alzheimer's disease, and semantic dementia. *Cognitive Neuropsychology*, *23*(6), 856–876.

Moscoso del Prado Martín, F., Kostić, A., & Baayen, R. H. (2004). Putting the bits together: An information-theoretical perspective on morphological processing. *Cognition*, *94*, 1–18.

Dubois, B., Feldman, H. H., Jacova, C., Dekosky, S. T., Barberger-Gateau, P., Cummings, J., Delacourte, A., Galasko, D., Gauthier, S., Jicha, G., Meguro, K., O'Brien, J., Pasquier, F., Robert, P., Rossor, M., Salloway, S., Stern, Y., Visser, P. J., & Scheltens, P. (2007). Research criteria for the diagnosis of Alzheimer's disease: Revising the NINCDS-ADRDA criteria. *Lancet Neurology*, *6*, 734–746. https://doi.org/10.1016/S1474-4422(07)70178-3

Engelmann, F., Granlund, S., Kolak, J., Szreder, M., Ambridge, B., Pine, J., Theakston, A., & Lieven, E. (2019). How the input shapes the acquisition of verb morphology: Elicited production and computational modelling in two highly inflected languages. *Cognitive Psychology*, *110*, 30–69.

Gor, K., & Jackson, S. (2013). Morphological decomposition and lexical access in a native and second language: A nesting doll effect. *Language and Cognitive Processes*, *28*, 1065–1091.

Granlund, S., Kolak, J., Vihman, V., Engelmann, F., Lieven, E. V. M., Pine, J. M., Theakston, A. L., & Ambridge, B. (2019). Language-general and language-specific phenomena in the acquisition of inflectional noun morphology: A cross-linguistic elicited-production study of Polish, Finnish and Estonian. *Journal of Memory and Language*, *107*, 169–194.

Hendrix, P., & Sun, C. C. (2020). A word or two about nonwords: Frequency, semantic neighborhood density, and orthography-to-semantics consistency effects for nonwords in the lexical decision task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. https://doi.org/10.1037/xlm0000819

Herdan, G. (1960). *Type-token mathematics: A textbook of mathematical linguistics*. The Hague: Mouton.

Hughes, C. P., Berg, L., Danziger, W. L., Coben, L. A., & Martin, R. L. (1982). A new clinical scale for the staging of dementia. *The British Journal of Psychiatry*, *140*, 566–572.

Ito, K., & Hutmacher, M. M. (2014). Predicting the time to clinically worsening in mild cognitive impairment patients and its utility in clinical trial design by modeling a longitudinal clinical dementia rating sum of boxes from the ADNI database. *Journal of Alzheimer's Disease*, *40*, 967–979.

Keuleers, E., Stevens, M., Mandera, P., & Brysbaert, M. (2015). Word knowledge in the crowd: Measuring vocabulary size and word prevalence in a massive online experiment. *The Quarterly Journal of Experimental Psychology*, *68*(8), 1665–1692.

Kirjavainen, M., Nikolaev, A., & Kidd, E. (2012). The effect of frequency and phonological neighbourhood density on the acquisition of past tense verbs by Finnish children. *Cognitive Linguistics*, *23*(2), 273–315.

Laine, M., & Virtanen, P. (1999). *WordMill lexical search program*. Centre for Cognitive Neuroscience, University of Turku.

Langacker, R. W. (2000). A dynamic usage-based model. In M. Barlow & S. Kemmer (Eds.), *Usage-based models of language* (pp. 1–63). Stanford, CA: CSLI.

Lenzi, D., Serra, L., Perri, R., Pantano, P., Lenzi, G. L., Paulesu, E., Caltagirone, C., Bozzali, M., & Macaluso, E. (2011). Single domain amnestic MCI: A multiple cognitive domains fMRI investigation. *Neurobiology of Aging*, *32*(9), 1542–1557.

Levenshtein, V. I. (1966). Binary codes capable of correcting deletions, insertions, and reversals. *Soviet Physics Doklady*, *10*, 707–710.

Lieberman, E., Michel, J.-B., Jackson, J., Tang, T., & Nowak, M. A. (2007). Quantifying the evolutionary dynamics of language. *Nature*, *449*, 713–716.

Lõo, K., Järvikivi, J., & Baayen, R. H. (2018). Whole-word frequency and inflectional paradigm size facilitate Estonian case-inflected noun processing. *Cognition*, *175*, 20–25.

Lõo, K., Järvikivi, J., Tomaschek, F., Tucker, B., & Baayen, R. H. (2018). Production of Estonian case-inflected nouns shows whole-word frequency and paradigmatic effects. *Morphology*, *28*, 71–97.

Lowrance, R., & Wagner, R. (1975). An extension of the string-to-string correction problem. *Journal of the Association of Computing Machinery*, *22*, 177–183.

Marcus, G. F., Pinker, S., Ullman, M. T., Hollander, M., Rosen, T., & Xu, F. (1992). Overregularization in language acquisition. *Monographs of the Society for Research in Child Development*, *57*, 1–182.

McKhann, G. M., Knopman, D. S., Chertkow, H., Hyman, B. T., Jack Jr., C. R., Kawas, C. H., Klunk, W. E., Koroshetz, W. J., Manly, J. J., Mayeux, R., Mohs, R. C., Morris, J. C., Rossor, M. N., Scheltens, P., Carrillo, M. C., Thies, B., Weintraub, S., & Phelps, C. H. (2011). The diagnosis of dementia due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's Dementia*, *7*, 263–269.

Meara, E. R., Richards, S., & Cutler, D. M. (2008). The gap gets bigger: Changes in mortality and life expectancy, by education, 1981–2000. *Health Affairs*, *27*(2), 350–360.

Nebes, R. D. (1989). Semantic memory in Alzheimer's disease. *Psychological Bulletin*, *106*(3), 377–394.

Niemi, J., & Niemi, S. (1987). Acquisition of inflectional marking: A case study of Finnish. *Nordic Journal of Linguistics*, *10*, 59–89.

Nikolaev, A., Ashaie, S., Hallikainen, M., Hänninen, T., Higby, E., Hyun, J., Lehtonen, M., & Soininen, H. (2019). Effects of morphological family on word recognition in normal aging, mild cognitive impairment, and Alzheimer's disease. *Cortex*, *116*, 91–103.

Nikolaev, A., Lehtonen, M., Higby, E., Hyun, J., & Ashaie, S. (2018). A facilitatory effect of rich stem allomorphy but not inflectional productivity on single-word recognition. *Applied Psycholinguistics*, *39*, 1221–1238.

Nikolaev, A., Pääkkönen, A., Niemi, J., Nissi, M., Niskanen, E., Könönen, M., Mervaala, E., & Soininen, H. (2014). Behavioural and ERP effects of paradigm complexity on visual word recognition. *Language, Cognition and Neuroscience*, *10*, 1295–1310.

Noble, J. M., Schupf, N., Manly, J. J., Andrews, H., Tang, M. X., & Mayeux, R. (2017). Secular trends in the incidence of dementia in a multi-ethnic community. *Journal of Alzheimer's Disease*, *60*(3), 1065–1075.

O'Bryant, S. E., Lacritz, L. H., Hall, J., Waring, S. C., Chan, W., Khodr, Z. G., Massman, P. J., Hobson, V., & Cullum, C. M. (2010). Validation of the new interpretive guidelines for the clinical dementia rating scale sum of boxes score in the national Alzheimer's coordinating center database. *Archives of Neurology*, *67*, 746–749.

Pinker, S. (1991). Rules of language. *Science*, *253*, 530–540.

Plunkett, K., & Marchman, V. (1993). From rote learning to system building. Acquiring verb morphology in children and connectionist nets. *Cognition*, *48*, 21–69.

Prasada, S., & Pinker, S. (1993). Generalisation of regular and irregular morphological patterns. *Language and Cognitive Processes*, *8*, 1–56.

Ramscar, M., Hendrix, P., Shaoul, C., Milin, P., & Baayen, R. H. (2014). The myth of cognitive decline: Non-linear dynamics of lifelong learning. *Topics in Cognitive Science*, *6*, 5–42.

Räsänen, S. H. M., Ambridge, B., & Pine, J. M. (2016). An elicited-production study of inflectional verb morphology in child Finnish. *Cognitive Science*, *40*, 1704–1738.

Rumelhart, D. E., & McClelland, J. L. (1986). On learning the past tenses of English verbs. In D. E. Rumelhart & J. L. McClelland (Eds.), *Parallel distributed processing: Explorations in the microstructure of cognition* (Vol. 2, pp. 216–271). Cambridge, MA: MIT Press.

Scarmeas, N., Albert, S. M., Manly, J. J., & Stern, Y. (2006). Education and rates of cognitive decline in incident Alzheimer's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, *77*(3), 308–316.

Stopford, C. L., Thompson, J. C., Neary, D., Richardson, A. M., & Snowden, J. S. (2012). Working memory, attention, and executive function in Alzheimer's disease and frontotemporal dementia. *Cortex*, *48*(4), 429–446.

Ullman, M. (2001). The declarative/procedural model of lexicon and grammar. *Journal of Psycholinguistic Research*, *30*, 37–69.

Ullman, M. (2004). Contributions of memory circuits to language: The declarative/ procedural model. *Cognition*, *92*, 231–270.

Ullman, M. T. (2016). The declarative/procedural model: A neurobiological model of language learning, knowledge and use. In G. Hickok & S. A. Small (Eds.), *The neurobiology of language* (pp. 953–968). Amsterdam: Elsevier.

van der Loo, M. (2014). The stringdist package for approximate string matching. *The R Journal*, *6*, 111–122.

Walenski, M., Sosta, K., Cappa, S., & Ullman, M. T. (2009). Deficits on irregular verbal morphology in Italian-speaking Alzheimer's disease patients. *Neuropsychologia*, *47*, 1245–1255.

Winblad, B., Palmer, K., Kivipelto, M., Jelic, V., Fratiglioni, L., Wahlund, L.-O., Nordberg, A., Backman, L., Albert, M., Almkvist, O., Arai, H., Basun, H., Blennow, K., de Leon, M., DeCarli, C., Erkinjuntti, T., Giacobini, E., Graff, C., Hardy, J., Jack, C., Jorm, A., Ritchie, K., van Duijn, C., Visser, P., & Petersen, R. C. (2004). Mild cognitive impairment–beyond controversies, towards a consensus: Report of the International Working Group on Mild Cognitive Impairment. *Journal of Internal Medicine*, *256*, 240–246.

Yu, J., Li, R., Jiang, Y., Broster, L. S., & Li, J. (2016). Altered brain activities associated with neural repetition effects in mild cognitive impairment patients. *Journal of Alzheimer's Disease*, *53*(2), 693–704.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Table S1. Pseudo-words used in the experiment (and their phonological similarity to real words, length, and bi- and trigram frequencies).