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A challenge to current models of past tense inflection: The impact of phonotactics

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Abstract

Is past tense production better modelled by a Single Mechanism or a Words and Rules model? We present data concerning a phenomenon that has not been considered by either model—regular past tense verbs with contrasting phonotactics. One set of verbs contains clusters at the inflected verb end that also occur in monomorphemic words (‘monomorphemically legal clusters’, MLC) whereas the other has clusters that can only occur in inflected forms (‘monomorphemically illegal clusters’, MIC). We argue that if children apply a morphological rule, phonotactics will not affect performance. Conversely, if children store past tense forms, they will perform better on verbs with MLCs because these clusters are more frequent. We investigated three populations—typically developing children, Grammatical-SLI (G-SLI) and Williams Syndrome (WS)—using past tense elicitation tasks. In Experiment 1 we reanalyse data from van der Lely and Ullman [van der Lely, H. K. J. & Ullman, M. (2001). Past tense morphology in specifically language impaired and normally developing children. *Language and Cognitive Processes, 16*: 177–217] and show that G-SLI children perform better on MLC verbs, whereas for typically developing children phonotactics do not affect performance. In Experiment 2 we replicate these findings in new groups of G-SLI and typically developing children. In Experiment 3 we reanalyse data from Thomas et al. [Thomas, M. S. C., Grant, J., Barham, Z., Gsodl, M., Laing, E., Lakusta, L., Tyler, L.K., Grice, S., Paterson, S. & Karmiloff-Smith, A. (2001) Past tense formation in Williams Syndrome. *Language and Cognitive Processes, 16*: 143–176] and show that phonotactics do not affect performance in individuals with WS. We argue that the results elucidate the underlying nature of morphology in these populations, and are better accommodated within a Words and Rules model of past tense acquisition.

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1. Introduction

An ongoing debate in psycholinguistic research concerns whether certain aspects of cognition employ the dual strategies of a symbolic rule-based system and an associative memory system (Marcus et al., 1992; Pinker, 1999; Pinker & Ullman, 2002), or whether these abilities can instead be modelled by a single mechanism comprising an associative memory network (Joanisse & Seidenberg, 1998; 1999; McClelland & Patterson, 2002). English past tense morphology has become a testing ground for these contrasting claims because two types of verbs exist—regular and irregular. The question is whether these two morphological strategies are served by separate cognitive mechanisms (a 'Words and Rules', WR, model) or a single mechanism (SM model). A huge literature devoted to this issue has been generated over the past twenty years, and some of the most fought-over evidence comes from how individuals with developmental or acquired language disorders perform on regular relative to irregular verbs in elicitation tasks.

In this paper we propose a novel approach to investigating whether inflection is better modelled by a WR or SM model. This approach focuses on phonotactic differences between two sets of *regular* past tense verbs. In this introduction we justify our concentration on such forms. We discuss their phonotactics and how these might be expected to impact on children's inflectional abilities. We also explain how phonotactics can be used to tease apart the WR and SM models, and why it is important to test the models' predictions in both typically developing and language-impaired populations.

We begin with a discussion of regular and irregular verbs. WR and SM models handle irregular verbs in the same way. Irregulars are considered to be lexically stored, with associative mapping between the phonological content of different forms of a verb (Joanisse & Seidenberg, 1999; Pinker, 1999; Rumelhart & McClelland, 1986). However, the models differ in how they handle regular verbs. In the WR model regular inflection is generated by a rule that adds the '-ed' suffix to the stem, and this rule is part of the morphological component of the grammar. In the SM model no such morphological component exists, so there is no categorical distinction between regulars and irregulars—whatever the verb, phonological features of the stem are associated with the phonological features of the past tense form. In the WR model the morphological rule for past tense formation applies to any regular verb regardless of its phonological make-up (Kim, Pinker, Prince, & Prasada, 1991; Prasada & Pinker, 1993). In contrast, the phonological characteristics of verb stems and their past tense forms are of central importance to the SM model. For the SM model, the apparent distinction between regulars and irregulars emerges as a consequence of phonological factors, such as regular stems and their corresponding past tense forms having much closer phonological overlap than do irregular stems and their past tense forms. For example, there is greater overlap between *yell* and *yelled* than there is between *sell* and *sold*.

There is a further important phonological difference between regular and irregular past tense forms—while irregulars have word-endings that are phonotactically identical to monomorphemic (i.e. uninflected) English words, regular past tense forms *can* have word-endings that are phonotactically different to those in monomorphemic words

(Burzio, 2002). Irregular past tense forms tend not to contain clusters, e.g. *took*, *swam*, *got*, *stood*, but if they do, e.g. *slept*, *built*, *spent*, *lost*, then those clusters are phonotactically legal in English, meaning that they also occur in monomorphemic words (c.f. *accept*, *stilt*, *tent*, *frost*). For the purposes of this paper we term such sequences ‘monomorphemically legal clusters’ (MLCs). Some regularly inflected forms also contain legal clusters, e.g. *crossed* (c.f. *frost*, *mist*), *scowled* (c.f. *bald*, *cold*), *dropped* (*opt*, *apt*). However, many regular past tense forms have clusters which can *not* occur in monomorphemic words, and are therefore illegal in English phonology e.g. *slammed*, *rushed* and *changed*. We term these sequences ‘monomorphemically illegal clusters’ (MICs).

Table 1 presents a comprehensive typology of irregular and regular inflected verb endings in English (assuming a non-rhotic accent, which the participants in our studies have). The list is long because vowel length, number of consonants, voicing and the obstruent/ sonorant distinction are all factors in determining the phonotactic legality of word-final sequences. The syllabic suffix, which is added to stems ending in /t/ and /d/, is *not* considered here because it does not create verb-end clusters, which are the focus of this paper.

Let’s first consider the phonotactics of monomorphemic words that end in /t/ or /d/. For our purposes there are two points to note:-

Clusters of voiced obstruent +/d/ are illegal, whatever the length of the preceding nucleus (see c, g).

Clusters of unvoiced obstruent +/t/ are legal when the preceding nucleus is short, but only /st/ is legal when the preceding nucleus is long (see b, f).

Now let’s consider the phonotactics of irregular verbs. If a particular verb-end pattern is not legal in a monomorphemic form, then that pattern will not appear in an irregular verb. There are certain gaps where patterns that we would predict to occur in irregulars, e.g. VVSt (see h), are not attested. These lexical gaps are surely due to historical accident, as there is no principled phonological reason why they should not occur.

In terms of the phonotactics of regular past tense forms, a suffix can attach to any regular verb stem, regardless of its stem-end phonology. Any gaps that occur are due to the suffix having to agree in voicing with the stem-final consonant. Therefore, /t/ is not permissible after a sonorant (see d and h). /d/ is not permissible after an obstruent/ obstruent cluster because such clusters must be unvoiced in English (e.g. /ask/, */azg/), and therefore the suffix must be /t/ (see k).

In the WR model the past tense suffix is added to the stem whatever the phonology of that stem (Kim et al., 1991; Prasada & Pinker, 1993). Although the issue of phonotactics has not been addressed by WR theorists, the model would logically predict no effect of verb-end cluster phonotactics on the acquisition of regular past tense inflection. SM models, while stressing the role of phonology in past tense formation, have likewise not articulated specific predictions regarding the impact of cluster phonotactics. Bybee (1995), for example, adopts an SM model whereby the regular past tense is a schema, just as irregular past tenses are. Schemas are generalisations about the shape of the past tense form. Unlike irregular schemas, however, the regular schema is entirely open in the way it defines the items to which it may apply, and so is equally likely to apply to forms of any

Table 1
Irregular and regular inflected verb endings in English

		Irregular		Regular
a	VVd	*made*, *rode*	VV-d	*allowed*, *spied*, *rowed*
		maid, *road*		*loud*, *wide*, *code*
b	VOt	*kept*, *left*, *lost*	VO-t	*missed*, *capped*, *packed*
		adept, *left* (adjective), *frost*		*mist*, *apt*, *pact*
c	VOd	_, _,_	VO-d	***robbed***, ***hugged***, ***judged***
		*, *, *		*, *, *
d	VSt	*felt*, *spent*	VS-t	_, _
		felt (noun), *tent*		*felt*, *tent*
e	VSd	*held*	VS-d	*yelled*, *conned*
		weld		*weld*, *pond*
f	VVOt	_, _, _	VVO-t	*paced*, ***seeped***, ***raked***
		paste, *, *		*paste*, *, *
g	VVOd	_, _, _	VVO-d	***caged***, ***dived***, ***raised***
		*, *, *		*, *, *
h	VVSt	_	VVS-t	_
		paint		*paint*
i	VVSd	*told*, *found*	VVS-d	*rolled*, *drowned*
		old, *round*		*cold*, *sound*
j	VOOt	_	VOO-t	*flexed*
		next		*next*
k	VOOd	_, _	VOO-d	_, _
		*, *		*, *
l	VSOt	_	VSO-t	*stomped*, ***winced***, ***helped***
		prompt		*prompt*, *, *
m	VSOd	_, _,	VSO-d	***plunged***, ***bronzed***
		*, *		*, *
n	VVSOt	_, _	VVSO-t	***pounced***
		*, *		*
o	VVSOd	_,	VVSO-d	***changed***
		*,		*

KEY: V = short (lax) vowel, VV = long (tense) vowel, and O = obstruent and S = sonorant. Monomorphemic forms are presented, where possible, beneath each verb. A '_' indicates that a particular past tense form is not attested, and a '*' indicates that a particular monomorphemic form does not occur. In bold are those regular verbs that do not have a monomorphemic counterpart, and whose phonotactics are hence 'illegal' in some way.

shape. Such a model would presumably be like a WR model in proposing no difference between MLCs and MICs. For most SM models, the emphasis on the effects of lexical frequency and the phonological attributes of the verb and its neighbours (e.g. Marchman, 1997; Rumelhart & McClelland, 1986) leads to the logical prediction that performance will be better for past tense forms ending in MLCs. This is because MLCs, appearing as they do at the end of both monomorphemic words and regular past tense forms, have higher frequencies than MICs, which occur at the end only of past tense forms.

The aim of this paper is to investigate whether past tense production is better modelled by a Single Mechanism or a Words and Rules model of cognition. To this end, we test the impact of verb-end cluster phonotactics on the past tense performance of three populations. In Experiments 1 and 2 we test the hypotheses against different groups of children with Grammatical-Specific Language Impairment (G-SLI) and children with typically-developing language skills. In Experiment 3 we test typically developing children and children and adults with Williams Syndrome (WS). We argue that comparing the performance of different populations allows us to tease apart the hypotheses in a way that focusing on just a single population cannot.

2. Experiments 1 And 2: past tense morphology in typically developing and G-SLI children

Children with G-SLI are a sub-group of the SLI population characterised by a persistent (they are aged nine years and over) and primary deficit in grammar, but by otherwise normal development (van der Lely, 2005; van der Lely, Rosen, & McClelland, 1998). These children perform particularly poorly on tests designed to probe core aspects of morphosyntax, such as the Test of Active and Passive Sentences (van der Lely, 1996) and the Verb Agreement and Tense Test (van der Lely, 2000), making more than 20% errors at an age when typically developing children very rarely make any. Many have difficulties with complex syllable structure, which result in the simplification of clusters (Gallon, van der Lely & Harris, submitted; Marshall, Harris & van der Lely, 2003). However, none of these children have articulation difficulties of the sort manifest in children with verbal dyspraxia—their speech for known words is clear.

Van der Lely and Ullman (2001) presented a past tense elicitation task to a group of eleven G-SLI children (mean age 11;03) and three groups of typically developing children matched on standardised measures of morphosyntax and vocabulary ('language ability', LA, controls). Children were presented with a lead-in sentence, e.g. 'Everyday I rob a bank', and then the elicitation sentence 'Yesterday, just like everyday, I …'. 60 verbs were used, divided between irregular and regular, high and low frequency, and existing and nonsense verbs.

The G-SLI children's production of irregulars was lower than that of the two groups matched for vocabulary, but not significantly different from the group matched on morphosyntax. However, their performance on regular past tense forms was significantly lower than that of all three LA groups. The main error type for all groups was the bare stem version of the verb (e.g. *rob* for *robbed*).

Van der Lely and Ullman interpreted their findings within the WR model. That G-SLI children lack the regularity advantage seen in the LA controls and show consistent frequency effects for both regulars and irregulars, whereas the LA controls do so only for irregulars, led the authors to conclude that (i) both groups retrieve irregular past tense forms from the lexicon and (ii) G-SLI children preferentially retrieve stored regular forms from the lexicon, whereas typically-developing children compose regular forms de novo. According to this interpretation, an impairment in building morphologically complex forms targets the morphological rule for regulars but leaves the selection of irregulars from the lexicon relatively spared (see also van der Lely, 2005; van der Lely & Christian, 2000). Thus G-SLI children preferentially store regulars as inflected whole forms, just as they do irregulars.

The WR interpretation has been criticised by proponents of SM models, who claim that a phonological impairment underlies the difficulty with regular morphology. One influential hypothesis claims that the deficit in SLI lies in the processing of rapidly-presented sequential information, which affects the processing of acoustic stimuli (Tallal & Piercy, 1973a; 1973b). This deficit is proposed to impact on the acoustically non-salient /t/ and /d/ inflections, resulting in poor phonological representations of past tense forms (Joanisse & Seidenberg, 1998; 1999; 2003; McClelland & Patterson, 2002). Importantly, it is the phonological properties of regular past tense forms that are proposed to place the suffix at risk of omission, not an impairment in a suffixation rule per se.

Studies by van der Lely, Rosen, and Adlard (2004) demonstrate that G-SLI children have no consistent auditory deficit, and that performance on tasks involving auditory discrimination does not correlate with phonological or other language abilities. These findings militate against an auditory deficit causing the morphological impairment in G-SLI (see also Manis & Keating, in press; Rosen, 2003). This of course does not rule out the possibility that auditory deficits existed at some earlier stage of development, but this hypothesis can only be tested through longitudinal studies, which have yet to be carried out.

In Experiment 1 we present a reanalysis of past tense production data collected by van der Lely and Ullman (2001) from children with G-SLI and typically developing children. The predictions are as follows. The logical prediction of the Words and Rules model is that if typically developing children do indeed form regular past tense forms by affixing '-ed' to a verb stem, then phonological factors such as frequency should not have an effect, and no advantage for MLCs is expected. In contrast, an SM model predicts that phonological factors such as frequency are relevant, and that typically developing children will therefore show an advantage for MLCs. Both models predict that the G-SLI group will be less impaired for MLCs. If, as van der Lely and Ullman claim, G-SLI children have an impaired morphological rule and preferentially store regular past tense forms as they do irregulars, then phonological factors such as cluster frequency are predicted to affect performance in this group, with better performance on verbs with MLCs. This is because the G-SLI children are in effect using a 'single mechanism' to produce past tense forms.

It is therefore the pattern of performance of the typically developing versus the G-SLI children with respect to phonotactics that distinguishes the two models. Whereas the WR model predicts qualitatively different performance for the typically developing and G-SLI groups, the SM model predicts that G-SLI children will behave similarly to typically developing children.

3. Experiment 1—Method

The verb stimuli selected by van der Lely and Ullman included 16 regular verbs, 10 of which are included in the subset analysed here (see also Ullman, 1999; Ullman & Gopnik, 1999). The procedure used to elicit past tense forms was of the form: 'Everyday I rob a bank. Yesterday, just like everyday, I …'. The G-SLI group comprised 11 children between the ages of 9;03 and 12;10, mean age 11;03. Three groups of typically developing children ($N=35$) provided language ability matched (LA) control groups. The youngest group (LA1 controls, mean age 5;09) were matched on tasks that tapped morphosyntactic abilities, and the LA2 and LA3 groups (mean age 6;11 and 7;11 respectively) were matched on tasks of vocabulary comprehension and expression. For further details of the methodology and of participant selection, see van der Lely and Ullman (2001).

A subset of the regular verbs was chosen that were identical with respect to phonological structural complexity in that their inflected forms all ended in a 2-consonant cluster. This subset of verbs was analysed with respect to phonotactic legality. The verbs were divided into two groups: 5 ending in MLCs, and 5 ending in MICs. The number of verbs is small because only 5 of the verbs used in the task contained MICs, and these were matched to verbs with MLCs whose mean past tense frequency was equivalent according to the 17.9 million word COBUILD corpus of the University of Birmingham, by the Centre for Lexical Information (CELEX) at the University of Nijmegen[1]. To ensure that the participants' familiarity with the verbs did indeed reflect the frequencies provided by the COBUILD frequency counts, van der Lely and Ullman (2001) carried out a stem familiarity task. This showed a high and significant correlation between the frequency counts and children's familiarity ratings for all groups, indicating that the COBUILD frequencies are an appropriate estimate for these children. Table 2 provides details of the past tense and lemma frequency counts. All frequencies are calculated by taking the natural log (ln) of 1+ the raw frequency (i.e. out of a total of 17.9 million).

In addition, we calculated the frequencies of verb-end clusters over the total number of tokens which end in that particular cluster. For example, in calculating the cluster frequency of /md/, we added up the number of tokens ending in *med*, e.g. *named*+ *seemed*+*screamed* etc., and *mbed* (where the /b/ is silent), e.g. *climbed*+*combed* etc. In calculating the frequency of legal clusters we summed all the inflected and uninflected tokens, e.g. for /st/ we added *just*+*raced*+*guessed* etc. This method is in line with Bernhardt and Stemberger (1998), who argue that it is the frequency of phonological sequences in the language as a whole that predict which regular forms are marked for tense, not frequency within the past tense domain.

Independent samples t-tests reveal that both conditions are well-matched for both past tense frequency and lemma frequency, $t(8)=0.081$, $p=0.937$, and $t(8)=0.249$, $p=0.809$, respectively. This matching is important because both past tense and lemma frequency could potentially influence inflection rates. In contrast, there are frequency differences for

[1] Excluded items are looked and chopped (both have MLCs), and scoured, marred, stirred and soared, which in the non-rhotic accents of our participants do not end in a cluster.

Table 2
Frequency of past tense forms and verb-end clusters

	Verb	Past tense	Frequency[a]	
			Lemma	Cluster
Monomorphemically legal clusters	Scowled	2.30	3.99	8.14
	Flapped	2.56	4.86	6.53
	Stalked	2.71	3.43	7.82
	Crossed	5.04	6.26	9.24
	Dropped	5.59	6.64	6.53
	Mean (SD)	**3.64 (1.55)**	**5.03 (1.39)**	**7.65 (1.15)**
	Tagged	2.94	4.61	3.69
Monomorphemically illegal clusters	Slammed	3.58	4.60	5.76
	Rushed	4.39	5.97	5.23
	Robbed	3.09	4.55	4.16
	Flushed	3.90	4.60	5.23
	Mean (SD)	**3.58 (0.59)**	**4.87 (0.62)**	**4.81 (0.85)**

[a] Counts are drawn from the COBUILD corpus in the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993).

MLCs and MICs: MLCs are significantly more frequent than MICs, $t(8)=4.422$, $p=0.002$.

4. Experiment 1—Results And Discussion

Table 3 presents the mean percentage of correct responses from the phonotactic analysis for the G-SLI group and all the control children grouped together. The mean percentage of correct responses for each of the control groups is also presented.

Because the data are not normally distributed we used non-parametric tests. First we investigated whether G-SLI and control children's responses were similarly affected by phonotactics. A Kruskal–Wallis test was used to investigate the group (G-SLI, LA controls)×difference between the MIC and MLC scores for each subject (MIC score minus MLC score). The interaction was significant ($\chi^2(1)=5.461$, $p=0.019$).

In the LA control group as a whole MIC verbs were inflected more often than MLC verbs, although a Wilcoxon signed ranks test revealed that this did not reach significance ($Z=-1.461$, $p=0.144$). We then analysed the control groups individually to see if any

Table 3
Mean percentage of correct responses for the G-SLI group, and the control groups (altogether, and individually)

	G-SLI	LA controls	LA1	LA2	LA3
	9;03–12;10 ($N=11$)	5;05–8;09 ($N=35$)	5;05–6;04 ($N=12$)	6;05–7;04 ($N=12$)	7;05–8;09 ($N=11$)
Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
MLC verbs	23.63 (17.48)	75.41 (28.08)	65.00 (30.90)	76.67 (28.07)	85.40 (25.01)
MLC verbs	12.73 (13.48)	80.57 (20.91)	68.33 (30.10)	76.67 (25.35)	98.18 (6.03)

responded differently to MLC and MIC verbs. For the LA1 and LA2 groups phonotactics had no significant effect on performance, $Z = -0.587$, $p = 0.557$, and $Z = -0.214$, $p = 0.831$ for LA1 and LA2 respectively. For the LA3 controls, however, MIC verbs were significantly easier than MLC verbs, $Z = -2.121$ $p = 0.034$. In contrast, a Wilcoxon signed ranks test comparing G-SLI performance on MLC and MIC verbs revealed that, as predicted by both the WR and SM models, the G-SLI group inflected MIC verbs significantly less often ($Z = -1.897$, $p = 0.029$, 1-tailed).

The results of the Experiment 1 indicate that cluster phonotactics affect past tense inflection of regular verbs in G-SLI children, but not in typically developing children between the ages of 5 and 8, although there is an advantage for MIC verbs in the oldest control group. However, we caution against using these results to draw strong conclusions with respect to the SM and WR models at this stage. Firstly, the stimulus set is small. Secondly, inflection rates amongst the G-SLI group are low—they scored less than 20% on these items. This raises the possibility that the different performance of the G-SLI children relative to the controls wouldn't be found at higher rates of inflection (and likewise the possibility that typically developing children would show a disadvantage for MIC verbs at lower rates of inflection, as the G-SLI group does. We return to this point in our general discussion). And thirdly, in 4 of van der Lely and Ullman's sentences (2 in each condition) the verb was followed by a consonant-initial word. Guy (1991) found that word-final /t/ and /d/ are more likely to be deleted in normal speech when the next word begins with a consonant. Ensuring that stimulus sentences are constructed so that each verb is followed by a vowel-initial word would reduce the likelihood of /t/ and /d/ being deleted for phonological rather than morphological reasons. We address all these potential problems in Experiment 2.

5. Experiment 2—Method

In Experiment 2, we further test the predictions of the SM and WR models with respect to verb-end cluster phonotactics by carrying out a new elicitation experiment, with new groups of G-SLI and typically developing participants.

We varied the presentation method in order to facilitate the production of correct responses. The children were introduced to two toy dogs. One of the dogs, called Kipper, was likely to be familiar to them from books and cartoons. The second was new to them, and was introduced as 'Bean Dog'. The explanation for the task was as follows. The experimenter reminded/told the child that Kipper is a very adventurous dog who does all sorts of exciting things. She also told the child that Bean Dog is one of Kipper's best friends, but that he gets very jealous of Kipper and all the adventures that Kipper has. She explained that Kipper had been busy doing lots of things recently. Bean Dog was jealous and wanted to tell everyone that he had been doing them too. The experimenter asked the child to help her to be the voice of Bean Dog and tell everyone the things that he has been doing. The lead in was as follows, e.g. 'Last week Kipper robbed a post office. Every week I rob a post office. Last week I …' In this way, the child was primed with both the bare stem and past tense forms of the verb, and we predicted that this would raise performance levels.

We increased the number of items in each condition to 8, while still carefully controlling for the same factors that were controlled in Experiment 1. The verbs and their characteristics are presented in Table 4. The full list of stimulus sentences is presented in Appendix A, and it can be seen that each verb was followed by a vowel-initial word. Two MLC and two MIC verbs are followed by a prepositional phrase—all other sentences contain a direct object phrase.

Independent samples *t*-tests reveal that both conditions are well matched for past tense frequency and lemma frequency, $t(14)=1.034$ $p=0.319$, and $t(14)=0.330$, $p=0.747$,

Table 4
Frequency of past tense forms and verb-end clusters

	Verb	Past tense	Frequencies[a]	
			Lemma	Cluster
Monomorphemically legal clusters (MLCs)	Yelled	3.74	5.67	8.14
	Wrapped	4.48	5.59	6.53
	Tossed	3.74	5.00	9.24
	Kissed	4.74	6.08	9.24
	Killed	5.81	7.21	8.14
	Packed	4.26	5.26	7.82
	Coughed	2.83	5.00	6.17
	Hopped	2.64	4.29	6.53
	Mean (SD)	**4.03 (1.03)**	**5.51 (0.87)**	**7.73 (1.21)**
Monomorphemically illegal clusters (MICs)	Hugged	3.00	4.55	3.69
	Hummed	2.48	4.88	3.76
	Robbed	3.09	4.55	4.16
	Fished	3.47	4.33	5.22
	Buzzed	2.40	6.67	5.01
	Touched	4.98	4.85	
	Judged	4.03	5.65	4.36
	Washed	4.66	6.62	5.22
	Mean (SD)	**3.51 (0.96)**	**5.36 (0.93)**	**4.53 (0.63)**

[a] Counts are drawn from the COBUILD corpus in the CELEX database (Baayen et al., 1993).

Table 5
Participant details for Experiment 2

Measure		G-SLI $N=14$	LA1 controls $N=14$	LA2 controls $N=14$
Age	Mean	12;03	6;00	9;06
	Range	9;09–16;08	4;06–7;05	7;06–12;00
TROG[a]	Raw, mean	12.86	10.76	16.43
	Raw, range	6–17	6–16	12–19
	z-score, mean	-1.67	−0.14	0.12
BPVS[b]	Raw, mean	79.93	60.00	94.21
	Raw, range	47–104	33–81	69–120
	z-score, mean	−1.67	0.28	0.28

[a] TROG, Test for Reception of Grammar; Bishop, 1983.
[b] BPVS, British Picture Vocabulary Scales; Dunn, Dunn, Whetton & Burley.

respectively. As was the case in Experiment 1, MLCs are significantly more frequent than MICs, $t(14)=6.634$, $p<0.001$.

Three new groups of children participated in this experiment. 14 G-SLI participants were selected according to the criteria used by van der Lely and Ullman. The children in this group ranged from 9;09 to 16;08, mean age 12;03. Because of the wider range in age group in this G-SLI group compared to that of van der Lely and Ullman, a slightly different matching procedure was used. Of the 28 typically developing children selected, 14 were matched to individual G-SLI children on raw scores of a test of sentence comprehension, the Test for Reception of Grammar (Bishop, 1983), and 14 were individually matched on raw scores of the British Picture Vocabulary Scales (Dunn, Dunn, Whetton, & Burley, 1997). The main analysis is based on the overall control group, but the results are also presented according to age. The controls were divided into two groups according to age, in order to give a picture of typical development. The Language Ability 1 (LA1) control group are aged 4;06–7;05, with a mean age of 6;00, and the Language Ability 2 (LA2) control group are aged 7;06–12;00, with a mean age of 9;06. Table 5 provides a table with matching details.

6. Experiment 2—Results and Discussion

Data from one participant in the LA1 group were discarded because her answers were at times muffled and therefore difficult to transcribe accurately. Correct responses to the elicitation task are shown in Table 6. Just as van der Lely and Ullman found in their task, the overwhelming proportion of errors for all groups was the bare stem response (77.78%, 90.02% and 80.45% of errors for G-SLI, LA1 and LA2 groups respectively).

Correct performance was analysed using a 2 (Group: G-SLI, LA controls) × 2 (Condition: MLC, MIC) ANOVA. This revealed significant main effects of group, $F(1, 39)=15.774$, $p<0.001$, and condition, $F(1, 39)=13.803$, $p=0.001$. The interaction between group and condition was significant, $F(1, 39)=5.948$, $p=0.019$. *T*-tests showed that for the G-SLI group, performance on MLC verbs was significantly higher than performance on MIC verbs, $t(13)=2.446$, $p=0.029$. For the LA1 and LA2 groups, however, the pairwise comparisons between the two conditions were not significantly different, $t(12)=1.000$, $p=0.337$, and $t(13)=1.749$, $p=0.104$ respectively. The pattern of correct performance is therefore MLC > MIC for the G-SLI group, but MLC = MIC for the controls.

To further test whether the differing cluster frequencies of MLC and MIC verbs have any effect on the performance of any of the participant groups, we ran 1-tailed correlations

Table 6
Mean percentage of correct responses for the G-SLI group, and the control groups (altogether, and individually)

	G-SLI Mean (SD)	LA controls Mean (SD)	LA1 Mean (SD)	LA2 Mean (SD)
MLC verbs	78.57 (23.22)	97.69 (5.55)	96.15 (7.93)	99.12 (3.34)
MIC verbs	65.18 (38.97)	94.91 (10.73)	94.23 (10.96)	95.54 (10.52)

between cluster frequency and inflectional accuracy for the 16 verbs taken together. For the G-SLI group we found a significant correlation between cluster frequency and correct inflection, $r=0.460$, $p=0.036$, but there was no significant correlation for either the LA1 controls, $r=0.204$, $p=0.225$, or the LA2 controls, $r=0.317$, $p=0.116$.

The results of Experiment 2 reveal that children with G-SLI perform worse on verbs with MICs than they do on those with MLCs, and support the findings of Experiment 1. The finding that the G-SLI group show a significant correlation between performance and cluster frequency supports the hypothesis that they are storing past tense forms. Recall that both the SM and the WR models predicted worse performance for the G-SLI group on MIC verbs. However, according to the SM model, children with typical language development should also show a disadvantage for MIC verbs. The control data in Experiment 2 are close to ceiling, because the lead-in that we introduced to raise performance in the G-SLI group, not surprisingly, also improved the control children's performance. This makes the non-significant differences between MLC and MIC verbs difficult to interpret, although the lack of a correlation between performance and cluster frequency suggests that storage is not a significant factor in these children's performance. Moreover, none of the control groups in Experiment 1 shows the advantage for MLC verbs that the SM model would predict. In fact, for the LA3 group, the advantage is actually for MIC verbs, a point we return to in the General Discussion section. The finding that the LA1 and LA2 groups performed equivalently on MLC and MIC verbs was predicted by the WR model.

Before we discuss the implications of our findings for the two models being tested, an important issue remains: we cannot exclude the possibility that all children with atypical language development, and not just those with G-SLI, might show a similar dissociation between MLC and MIC verbs. We test this possibility in the next experiment by investigating the impact of phonotactics on a group of children and adults with Williams Syndrome. In addition, with a new set of control data, we can further probe the abilities of typically developing children, and determine whether they reveal an advantage for MLCs (as the SM model predicts) or equivalent performance on each (the prediction of the WR model).

7. Experiment 3: past tense morphology in typically developing children, and children and adults with WS

In this final experiment we further test the predictions of the SM and WR models with regards to phonotactics, this time by analysing data collected from a second population with atypical language development: children and adults with Williams Syndrome (Thomas et al., 2001). WS is a rare genetic disorder characterised by a specific physical, cognitive and behavioural phenotype. Within cognitive skills, verbal abilities are superior to visuo-spatial abilities, although language performance falls below that found in chronological age-matched controls. Despite the relative strength of language skills, linguistic development is uneven.

It has been claimed that WS individuals show the opposite pattern of performance to SLI children on regular versus irregular verbs (Pinker, 1991). Clahsen and Almazan

Table 7
Percentage of correct responses for the WS and typically developing groups

	WS mean (SD)	Control mean (SD)
MLC verbs	77.41 (22.96)	77.33 (32.85)
MIC verbs	85.28 (22.52)	80.50 (27.13)

(1998), using the same elicitation task as van der Lely and Ullman (2001), revealed that success on regular verbs was equivalent to that of mental age-matched controls, whereas success on irregulars was much lower than controls. Clahsen and Almazan claim that irregular verbs are selectively impaired, whereas the rule-based inflection of regulars is in line with mental age. Using the WR framework they propose that a selective deficit affects representation of, and access to, word-specific knowledge. However, there were only 4 WS participants in that study, and the control participants performed at much higher levels on the irregular verbs than was the case in van der Lely and Ullman's study.

Thomas et al. (2001) used van der Lely and Ullman's task in order to replicate Clahsen and Almazan's (1998) study. They had a larger group of 18 WS participants (age range 10;11–53;03, mean 22;08) and three groups of typically developing children, the youngest of which (mean age 6;00) was the closest in terms of past tense performance to the WS group. Although the WS group did not show a selective deficit for irregulars when compared to this control group, Thomas et al. argue that irregular morphology in WS is atypical. Importantly, in WS regular morphology is not believed under either account to be impaired relative to control groups. Reanalysing the data from this study[2] with respect to phonotactics, in exactly the same way as we did for the G-SLI and typically developing data in Experiment 1, allows us to test the following hypotheses. The WR model predicts that only individuals with a language impairment in morphological rule use, but not all individuals with atypical language, will show an advantage for verbs with MLCs. In other words, the WR model predicts that the WS group will, like their typically developing controls, show no effect of phonotactics. In contrast, the SM model predicts that the WS population and their typically developing controls will both show an advantage for MLC verbs.

8. Experiment 3—Results and Discussion

The results of the analysis are presented in Table 7. We compare the performance of the WS group with that of the youngest control group (age range 5;05–6;04, mean age 6;00) in Thomas et al.'s study, as this group provides the best match to the WS group in terms of past tense performance. The most common error type from the WS and control groups was the bare stem form of the verb (Thomas et al., 2001)

A 2 (Group: WS, control)×2 (Phonotactics: MLC, MIC) ANOVA revealed no significant main effects of group, $F(1,26)=0.007$, $p=0.935$, or of phonotactics, $F(1,26)=3.149$, $p=0.088$, and no interaction between these two factors. Commensurate with

[2] We are most grateful to Michael Thomas and Annette Karmiloff-Smith for allowing us to reanalyse their data.

previous analyses we also computed individual *t*-tests for each participant group, comparing performance on MLCs and MICs. *T*-tests revealed no significant difference between MLCs and MICS for the control group, $t(9) = -0.802$, $p = 0.443$, and one approaching the significance level for the WS group, $t(17) = -1.917$, $p = 0.072$. Note that the weak trend in the WS group is in the direction of a disadvantage for MLC verbs, in contrast to the finding of a disadvantage for MIC verbs in the two groups of G-SLI children that we tested in Experiments 1 and 2.

These results confirm the predictions of the WR model that individuals typically developing language, as well as those with atypical language development but no morphological impairment, such as WS, are unaffected by verb-end cluster phonotactics.

9. General discussion

This paper has used a novel approach to investigating whether past tense production is better modelled by a Single Mechanism or a Words and Rules model of cognition, by testing the effects of verb-end cluster phonotactics in three populations: children with Grammatical-SLI, typically developing children, and children and adults with Williams Syndrome.

The results from our three experiments reveal that children with G-SLI show a different pattern of performance with respect to verb-end phonotactics when compared to typically developing children and individuals with WS. Children with G-SLI find verbs ending in monomorphemically illegal clusters (MICs) harder to inflect. In contrast, typically developing children between the ages of 4 and a half and 12, together with children and adults with WS, show no effect of phonotactics on their past tense performance. We argue that this different performance with respect to phonotactics provides insight into the nature of morphology in these groups.

Crucially, we interpret the lower performance amongst G-SLI children on verbs with MICs as being further evidence of a *morphological* deficit in this population. If, as van der Lely and colleagues claim (van der Lely & Christian, 2000; van der Lely & Ullman, 2001), G-SLI children have to rely on the storage of regular past tense forms, then the frequency of clusters at the inflected verb end is predicted to affect storage—higher frequency clusters are likely to be stored more effectively than low frequency clusters. Similarly, if G-SLI children create past tense forms by analogy, then they are predicted to create forms with higher frequency clusters more effectively than those with low frequency clusters. MLCs are more frequent than MICs because the former occur in both suffixed and monomorphemic forms, whereas the latter only occur in monomorphemic forms.

A possible and alternative explanation is that the G-SLI group's findings of worse performance on MIC verbs is caused by a phonological deficit. However, the following arguments militate against such an explanation. First, despite the claims of some researchers that children with SLI have an input-processing deficit that hampers their perception of the non-salient '-ed' ending and interferes with building phonological representations of past tense forms (Joanisse & Seidenberg, 1998; McClelland and Patterson, 2002), no consistent auditory deficits are implicated in G-SLI (van der Lely et al., 2004). Furthermore, it is difficult to see what makes MICs 'less salient' than MLCs:

in what way is /bd/ less salient than /pt/, thereby posing greater processing difficulties? Findings that children with G-SLI produce inflectional morphemes in ungrammatical contexts, for example inside compounds such as **rats-eater* (van der Lely & Christian, 2000), and Wh-questions such as *'Which door did it creaked?' (van der Lely & Battell, 2003) indicate that errors with inflection cannot be easily explained by an impairment in perception.

A second possible explanation is that an articulation deficit is responsible for the difference between the MLCs and MICs. Once again, we think this is unlikely. All clusters contained two consonants, and so did not differ in syllabic complexity. It is true that a voiced obstruent MIC such as /gd/ is more challenging to produce than an unvoiced obstruent MLC such as /kt/, because vocal fold activity is hard to sustain over a sequence of two obstruents, but as far as we know no-one has ever proposed that SLI children have difficulties producing voicing. This is of course a hypothesis that should be tested, but in the meantime it is just speculative.

At this stage the qualitatively different patterns of performance in the G-SLI group compared to WS group and several groups of typically developing children lead us to conclude that the G-SLI group have different underlying mechanisms for constructing regular past tense forms. A single mechanism model, one where the regulars are retrieved from analogical memory and where cluster frequency affects performance, can account for the G-SLI data, but *only* the G-SLI data. The fact that the typically developing and WS groups are not affected by frequency factors leads us to conclude that they are creating regular past tense forms in a different way to the G-SLI children, through the use of a rule that adds the past tense suffix to the verb stem.

Thus we argue that the data we have presented here, from a previously unexplored source, add to the growing body of work showing that G-SLI children have a morphological deficit. In an earlier test of the hypothesis that G-SLI children preferentially store inflected forms, van der Lely and Christian showed that G-SLI children include both regular and irregular plural forms inside compounds (*mice-eater*, **rats-eater*), whereas typically developing children virtually only use irregular plurals inside compounds. The frequency effects for regular and irregular verbs amongst the G-SLI children in van der Lely and Ullman's (2001) past tense study, while the typically developing children showed frequency effects only for irregulars, and the lack of regularity advantage for the G-SLI group, provide further evidence of a morphological deficit in G-SLI. All these data tell a consistent story: that G-SLI children's performance is not just worse than that of language-matched controls, but is qualitatively different. In each case, a WR model, whereby the morphological rule is impaired in G-SLI, can account for both the typically developing and G-SLI children's performance.

The perceptive reader will have noted that in Experiment 1 the older typically developing children (the LA3 group) showed a significant advantage for MIC verbs, and we have postponed a discussion of this finding until now. This finding was not predicted by either the WR or the SM model, and so deserves our attention. Our explanation is this: MICs reveal morphological complexity by indicating the presence of the stem-suffix boundary (*slammed*, *robbed* and *rushed* can only be past tense forms), whereas MLCs leave the word ambiguous between an inflected and an uninflected form (/mist/ is both inflected *missed* and monomorphemic *mist*). To further stress the point, MICs provide an unambiguous cue for learning about past tense-ness. It is an intriguing question as to whether children can use this cue to learn verb paradigms. We would be very cautious about interpreting our data in this way, given that the two younger control groups did not show an advantage for MICs. On the other hand, there was a trend in this direction for the WS group. Therefore it might be worth investigating in future work whether groups that are good at regular morphology are able to use verb-end cluster phonotactics as a means of parsing past tense verbs, and whether they are able to use this cue on their way to discovering a suffixation 'rule'.

To further test our interpretation that the mechanisms underlying regular inflection in G-SLI and typically developing children are indeed different, we would wish to see the following: data confirming the pattern we have found in typical development, whereby phonotactics has no effect on regular past tense production, is present at an even younger age. These data might help us to elucidate the mechanisms by which morphological productiveness arises. How the child switches from storing regular past tense forms to using them productively has been awkward to accommodate within WR models (Bybee, 1995). Although we have not collected such data ourselves, Tolbert, Tyler, and Lewis (2003) tested 40 three- and four-year olds on verbs containing legal and illegal obstruent clusters and found no difference in performance on those two conditions for either age group. Tolbert et al.'s results suggest that children as young as three are able to use morphological rules.

The predictions for how the different populations will treat English third person singular forms (e.g. *runs*, *loves*) and regular plurals are harder to make, given that the legal/illegal cluster divide is not as clear for clusters that end in /s/ and /z/. Very few monomorphemic words end in a sonorant +/z/ cluster (*bronze*, *lens* are amongst the few examples in non-rhotic accents, and are low frequency), or in an obstruent +/s/ or /z/ cluster other that /ks/ (*lapse*, *copse*, etc. are also low frequency). In any case, it is possible that SLI children do not have a difficulty with plural formation (Rice & Wexler, 1996), or at least the deficit may not be as severe as the tense deficit (Marshall, 2004). Thus the impact of phonotactics might only be seen in verb morphology, which is recognised as also being syntactically complex and an area of particular weakness in SLI (Leonard, 1998; Rice, Wexler, & Cleave, 1995; van der Lely, 2005).

10. Conclusion

In conclusion, this study has revealed a new avenue for testing the Single Mechanism and Words and Rules models of morphology. We claim that regular verb-end phonotactics can be used as a tool for revealing the underlying nature of morphology in different populations. Our findings showing G-SLI children's particularly poor performance for MIC verbs provide further support the hypothesis that they are impaired in morphological rule formation, while the lack of phonotactic effects in typically developing and WS groups suggests that those populations use a morphological rule to construct regular past tense forms. We argue that models of morphology need to be able to account for the impact of phonotactics on both typically developing and language-impaired populations, and that such a research program will enhance our understanding of the language faculty.

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Appendix A. Stimulus sentences for Experiment 2

Sentences with MLC verbs

(1) Yesterday Kipper yelled at his mum. Every day I yell at my mum. Yesterday I…
(2) Yesterday Kipper wrapped a present. Everyday I wrap a present. Yesterday I…
(3) Yesterday Kipper tossed a pancake. Everyday I toss a pancake. Yesterday I…
(4) Yesterday Kipper kissed a girl. Everyday I kiss a girl. Yesterday I…
(5) Last week Kipper killed a rat. Every week I kill a rat. Last week I…
(6) Yesterday Kipper packed a lunchbox. Everyday I pack a lunchbox. Yesterday I…
(7) Last winter Kipper coughed a lot. Every winter I cough a lot. Last winter I…
(8) Last night Kipper hopped around the bed. Every night I hop around the bed. Last night I…

Sentences with MIC verbs

(9) Yesterday Kipper hugged a friend. Everyday I hug a friend. Yesterday I…
(10) Last night Kipper hummed a tune. Every night I hum a tune. Last night I…
(11) Last week Kipper robbed a post office. Every week I rob a post office. Last week I…
(12) Yesterday Kipper fished in the river. Everyday I fish in the river. Yesterday I…
(13) Yesterday Kipper buzzed at a bee. Everyday I buzz at a bee. Yesterday I…
(14) Yesterday Kipper touched a flower. Everyday I touch a flower. Yesterday I…
(15) Last year Kipper judged a competition. Every year I judge a competition. Last year I…
(16) Yesterday Kipper washed a blanket. Everyday I wash a blanket. Yesterday I…

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