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Tense morphology in German agrammatism

The production of regular, irregular and mixed verbs

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This study investigates tense morphology in agrammatic aphasia and the predictions of two accounts on processing of regular and irregular verbs: the Dual Mechanism Model, that is, for aphasic data, the Declarative/Procedural model, and the Single Mechanism approach. The production of regular, irregular and mixed verbs in the present, simple past and past participle (present perfect) was tested in German by means of a sentence completion task with a group of nine speakers with agrammatic aphasia. The results show a difference between regular verbs and irregular verbs. Mixed verbs were equally difficult as irregular verbs. A frequency effect was found for irregular verbs but not for regular and mixed verbs. A significant difference among the correctness scores for present tense and simple past forms was found. Simple past and past participle were significantly more difficult than present tense. Error types were characterized by pure infinitive responses and time reference errors. Neither of the above accounts is sufficient to explain these results. Correctness scores and error patterns for mixed verbs suggest that such minor lexical patterns can be useful in finding new evidence in the debate on morphological processing. The findings also highlight time reference as well as language specific characteristics need to be taken into consideration.

Keywords: agrammatism, tense, regular and irregular verbs, mixed verbs,
inflectional morphology, time reference

There is a long-standing debate on how regular and irregular simple past verb forms are represented and processed (Pinker & Prince, 1988; Rumelhart & McClelland, 1986). Data from individuals with brain damage that results in a grammatical deficit may shed light on this issue. At the same time, new questions arise: Are the problems agrammatic speakers encounter with (regular and irregular) simple past

verbs and past participles caused by the factor regularity/irregularity or by other factors instead, for example, by the fact that they refer to the past.

In the current study, we examine the production of regular, irregular and mixed present and simple past verbs as well as participles in a group of German speaking agrammatic individuals. Although German is typologically quite close to English, it has a much richer inflectional paradigm and interesting minor lexical patterns (i.e., mixed verbs) which allow for testing claims about the processing and representation of inflectional morphology.

Tense Morphology in German

Verb classes are illustrated in Table 1 for third person singular (3sg) present tense, simple past and past participle.

For regular present tense, *-t* is suffixed to the verb stem. Simple past is formed by attaching the tense suffix *-te* to the verb stem. Regular present perfect is composed of the auxiliary *haben* or *sein* plus the past participle, which is formed by affixing the regular suffix *-t* to the verb stem. The prefix *ge-* is generally affixed to verbs that are stressed on the first syllable regardless of whether they are regular or irregular (Clahsen, 1999; Wiese, 1996). Irregular verbs in the present tense all carry the regular affix *-t*. Stem vowel changes take place for some irregular present tense verbs. Irregular simple past forms do not carry an inflectional morpheme. Instead, they display stem vowel changes (e.g., *sitzt-saß* ‘sits-sat’). Irregular past participle forms carry the irregular suffix *-n* and may or may not show stem vowel changes.

There is another class of verbs which is morphologically interesting. Those verbs carry traits of regular and irregular verb classes and are called ‘mixed verbs’. Historically, mixed verbs are not a homogenous class. This class consists of verbs such as *bringen* ‘to bring’, preterit-present verbs (e.g., *wissen* ‘to know’), and *Rückumlaut* verbs (e.g., *brennen* ‘to burn’). Preterit-present verbs are strong verbs which have lost their original present tense forms and came to use simple past forms in the present tense instead. Simple past forms adopted a present tense reference and the new simple past forms were affixed with *-te* (Elsen,

Table 1. Verb classes in German

	Regular	Irregular	Mixed
Infinitive	<i>spielen</i> ‘to play’	<i>sprechen</i> ‘to speak’	<i>rennen</i> ‘to run’
Present tense	<i>spielt</i>	<i>spricht</i>	<i>rennt</i>
Simple past, 3sg	<i>spiel-te</i>	<i>sprach- Ø</i>	<i>rann -te</i>
Present perfect/past participle	<i>ge- spiel -t</i>	<i>ge- sproch -en</i>	<i>ge- rann -t</i>

2011, p. 195). Rückumlaut verbs used to be weak verbs and are affixed *-te* in simple past. The vowel change which is evident in simple past and past participle is called ‘Rückumlaut’ although this term, going back to Jacob Grimm, is not quite accurate (Elsen, p. 196). Mixed simple past forms show stem changes and carry the regular simple past affix *-te*. Mixed past participles also display stem changes. They are suffixed with the regular past participle suffix *-t* (see Table 1). Mixed present tense verbs are regularly inflected except for the preterit-present verbs belonging to that class which show stem vowel changes and irregular *ø*-affixation.

Despite the heterogeneity in their historical development, all mixed verbs display stem changes in simple past and past participle. Thus, mixed verbs are similar to irregular verbs because those stem changes are just as idiosyncratic and unpredictable as the ones in irregulars (Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1995). The suffixation patterns follow the regular paradigm, which makes mixed verbs morphologically similar to regular verbs. Finally, mixed verbs pair with regulars in phonological aspects because of their similar morphological structure.

The processing of regular and irregular verbs

Assumptions on how regulars and irregulars are processed and represented in the brain differ greatly. Important questions are whether morphologically complex words are parsed or retrieved from memory and whether this is done by separate cognitive mechanisms (Smolka, Zwitserlood, & Rösler, 2007). An influential approach is the Dual Mechanism Model (DMM), also known as ‘words and rules theory’ (Clahsen, 1999; Pinker & Prince, 1994; Pinker & Ullman, 2002; Ullman, 2004). It assumes that the processing and representation of regulars and irregulars relies on two different routes that are subserved by separate cognitive mechanisms. Hence, verb forms that are derived by a rule are conceived as ‘regular’. Verb forms that are not derived by a rule are considered to be ‘irregular’ and stored as lexical entries in memory.

On the morphological level, the DMM is complemented by Minimalist Morphology (Wunderlich & Fabri, 1995). According to this approach, regulars are generated by affixation. Irregulars are stored as structured lexical entries with its modified stems also stored in memory (see Figure 1).

Stem forms are the base “on which affixation can operate” (Wunderlich, 1997, p. 268). Modified stems are underspecified because only modifications from the mother node are represented on the sub node. Remaining features are inherited from the mother node.

Alternative approaches assume a single cognitive mechanism for the processing of regular and irregular verbs that draws on phonological and semantic knowledge (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002; Rumelhart &

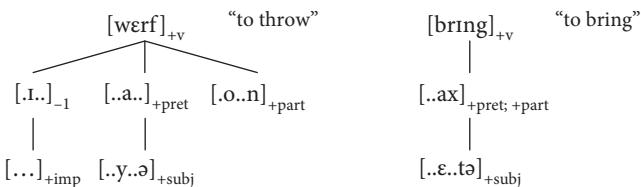


Figure 1. Structured lexical entry for the irregular verb *werfen* 'to throw' and the mixed verb *bringen* 'to bring' (adapted from Wunderlich & Fabri, 1995).

McClelland, 1986). This mechanism plays a differential role in processing regulars and irregulars. In this approach, semantic knowledge is relevant for all verbs, but it only plays a minor role in the formation of regular simple past. The rather consistent mapping between stem and simple past form is thought to rely on phonological processes. For irregular simple past forms there is no such consistency and, therefore, semantic knowledge becomes relevant.

Tense morphology in agrammatic aphasia

Agrammatic language production is characterized by simplified syntax, substitutions and/or omission of bound morphemes and function words, for instance prepositions and articles. Agrammatic speakers mainly rely on the use of content words, whereas nouns appear to be better preserved than verbs (e.g., Burchert & Druks, 2000). Investigating the characteristics and the underlying deficit in agrammatic aphasia allows for theorizing about the nature of the impairment and about language organization in the brain. Thus, difficulties agrammatic speakers display and the errors they make with inflectional morphology give insights into the representation and processing of inflectional morphology in the brain.

In accordance with the DMM (Pinker & Prince, 1994), Ullman et al. (1997) have proposed the Declarative/Procedural (DP) model. They reported that individuals with anterior brain lesions and agrammatic aphasia as well as individuals with Parkinson's disease perform poorly on regular simple past forms while the production of irregular verbs in simple past remains intact. The opposite pattern was found in patients with posterior aphasia and Alzheimer's disease. This double dissociation was taken as evidence for a dual organization of the mental language faculty (Ullman, 2001, 2004).

Proponents of single mechanism approaches argue that the dissociation between regular and irregular inflection is attributable to phonological or semantic deficits (Bird, Lambon Ralph, Seidenberg, McClelland, & Patterson, 2003; Braber, Patterson, Ellis, & Lambon Ralph, 2005; Joanisse & Seidenberg, 1999). Since *-ed* is affixed, English regular simple past forms consist of more syllables and are longer

on average. Therefore, English regular simple past forms are considered to be phonologically more complex than irregular simple past forms. Bird et al. (2003) tested a group of ten non-fluent English aphasic speakers to see whether the advantage for irregular verbs persisted if the material is matched for phonological complexity. The results showed a similar impairment for irregular and regular verbs. Therefore, Bird et al. concluded that the putative deficit for regular verbs observed in Ullman et al. (1997) was in fact due to a phonological deficit.

In English (ir-) regularity is confounded with the presence and absence of affixes (Penke, Janssen, & Krause, 1999). Therefore, setting apart an impairment of regular inflection from an impairment which affects affixes in general is not possible. To avoid this confound, Penke et al. (1999) tested the production of German regular and irregular past participles, both of them involving affixation. Eight out of eleven agrammatic participants made significantly more errors with irregular participles. The qualitative error analysis indicated that regular participle formation was intact because the errors with irregular participles were mainly regularization errors. Penke et al. concluded that irregular participles can be selectively impaired, and that their data support a dualistic nature of inflection.

Based on Penke et al. (1999), the study by Penke and Westermann (2006) included data of two more German and twelve Dutch agrammatic speakers. They found that both groups made significantly more errors with irregular participles in a sentence completion task. Ten out of the thirteen German and seven out of twelve Dutch agrammatic participants showed a selective impairment for irregular past participle forms. Penke and Westermann reasoned that it is not regular but irregular inflection which is selectively impaired in German and Dutch agrammatic aphasia. Subsequently, they proposed a variation of the Single Mechanism approach in which they postulate a global deficit as the reason for selective impairments of regular or irregular inflection.

Moreover, Penke and Westermann (2006) maintain that language specific differences in the status of inflectional affixes are responsible for cross-linguistic differences in the data (quoting Bates, Friederici, & Wulfeck, 1987). The idea is that in languages with sparse inflectional morphology, such as English, agrammatic speakers may omit inflectional endings. Since in English omission errors in tense inflection can occur for regular verbs but not for irregular verbs such an outcome would naturally look like a deficit for regular inflection. In languages with rich inflectional morphology, such as German, inflectional endings are less likely to be omitted because they are syntactically more relevant.

In two studies investigating finite and non-finite verb production in Dutch, no difference was found for regular versus irregular simple past and participles, neither for agrammatic speakers (Bastiaanse, 2008) nor for individuals with Parkinson's Disease (Colman et al., 2009).

In summary, there is no consensus on whether an impairment of regular or irregular inflection is characteristic of agrammatic aphasia, and, consequently, the nature of the underlying deficit remains unclear. A meta-analysis by Faroqi-Shah (2007) showed that studies in the field between 1980 and 2007 revealed no consistent pattern of impairment. For sentence production, Faroqi-Shah analyzed a total of 78 data sets whereby 49 of these came from English speaking aphasic individuals. One study each investigated Greek, Spanish, Italian, Dutch and German. The review revealed great methodological variety. In only two of 13 studies items were matched for phonological aspects. Only seven studies matched for frequency. As a consequence, the results across studies show great variability. Ten data sets out of 78 showed lower accuracy on regulars compared to irregulars. Remarkably, nine out of these ten data sets came from English speaking subjects. 26 data sets showed lower accuracy on irregulars. For the remaining 42 data sets, no difference was found. These findings raise the possibility that language specific factors underlie the deficit. Thus, the meta-analysis by Faroqi-Shah underscores the need for cross-linguistic investigations as well as replication of previous findings.

Time reference in agrammatic aphasia

Tense inflection in agrammatic aphasia has been investigated for two reasons: the question was if tense is more impaired than agreement and if an impairment for tense reflects an underlying morpho-syntactic deficit or rather a problem in time reference. The debate began with a series of studies exploring tense inflection from a purely syntactic point of view (Burchert, Swoboda-Moll, & De Bleser, 2004, 2005; Friedmann & Grodzinsky, 1997; Wenzlaff & Clahsen, 2004, 2005). In a study examining oral production of finite and non-finite verbs, Bastiaanse (2008) found that tense inflection itself may not be the cause of the underlying deficit. Her data showed that simple past (past imperfect) is more difficult for Dutch agrammatic speakers than present tense and that participles are more difficult than infinitives. Based on these findings, Bastiaanse proposed a hierarchy according to which the production of verb forms becomes gradually harder with verbs referring to the past being particularly difficult for agrammatic speakers. In a later paper (Bastiaanse et al., 2011), it was argued that this is due to the need for discourse linking whenever a verb form referring to the past is involved (Zagona, 2003). Discourse linking has been shown to be difficult for individuals with Broca's aphasia (Avrutin, 2000). Present verb forms are not discourse linked and, therefore, easier to produce and comprehend.

Clahsen and Ali (2009) came to different conclusions. They tested English agrammatic speakers on tense marking, subject-verb agreement and subjunctive

mood in a forced choice sentence completion task and a grammaticality judgment task. While they found a general impairment for tense but not for subject-verb agreement, and subjunctive mood, they did not find a significant difference in the production of past and present tense verb forms. However, as Bastiaanse et al. (2011) has argued, this finding may be attributed to the nature of the task as it did not involve pure oral production, but written multiple choice tasks.

Aims and predictions

In the current study, the production of regular, irregular and mixed verbs in present tense, simple past and present perfect/past participle is tested in German agrammatic and non-brain-damaged speakers by means of a fill blank sentence completion task. One question this study aims to answer is whether regular and irregular verbs dissociate in German agrammatic aphasia.

Single and dualistic approaches predict different outcomes (see Table 2). Testing mixed verbs allows us to investigate the influence of phonological complexity as suggested by the Single Mechanism account (Bird et al., 2003) because both are suffixed in simple past and past participle. This allows us to match both forms closely for phonological complexity. Therefore, if phonological aspects are decisive, regulars should pattern with mixed verbs across all time frames. In present tense, no difference between verb classes is expected because verbs are phonologically similar in present tense.

Thus, the critical conditions are simple past and past participle. For simple past, the prediction for regular/mixed verbs is that they should be more difficult than irregular verbs because regular and mixed verbs in simple past involve suffixation whereas irregulars do not. In line with Bird et al.'s (2003) argumentation, the lack of suffixation makes irregulars phonologically simpler. They consist of one syllable and contain a smaller number of phonemes, which has been shown to be an important predictor for accuracy in aphasic language production (Nickels & Howard, 2004). For past participles, on the other hand, irregular forms should have lower accuracy scores than regular/mixed verbs if phonological factors influence the production of tense morphology. Irregular past participles contain more syllables and have a higher number of phonemes on average.

Dualistic models of inflection such as the DMM and, for aphasic data, the DP model, explain the dissociation between regulars and irregulars by means of distinct cognitive mechanisms underlying their production. In such an approach, brain damage that results in a grammatical deficit would affect rule based affixation processes. Hence, the production of regular verbs should be impaired, while the production of irregulars should remain intact (cf. Ullman, 2004).

Table 2. Predictions for Regular, Irregular and Mixed Verbs across Time Frames

	Time Frame	Prediction
Single Mechanism model	Present tense	regular = mixed = irregular
	Simple past	regular = mixed < irregular
	Past participle	irregular < regular = mixed
DMM/DP (structured lexical entries)	all time frames	regular = mixed < irregular
DMM/DP (holistic representation)	all time frames	regular < mixed = irregular

Neither the DMM nor the DP model is explicit about the representation and processing of mixed verbs. However, the DMM subscribes to the general principle that “the unpredictable must be stored” (Pinker & Prince, 1994, p. 342) and because stem changes in mixed verbs are just as unpredictable as stem changes in irregular verbs, Marcus et al. (1995, p. 220) assume that “mixed verbs or their stems must be stored”.

Adopting the DP model and assuming that mixed verbs are represented as structured lexical entries, the inflectional process should be applied to the stored modified stem (Wunderlich & Fabri, 1995). Since (rule-based) affixation processes are hypothesized to be disrupted in anterior aphasia, participants with agrammatism should fail to realize inflectional endings but preserve the stem change. Thus, regulars and mixed verbs should be equally impaired in agrammatic language production across *all* time frames alike. The irregular participle affix *-n* is assumed to be part of the modified stem (p. 255) and, thus, not affected by a disruption of the affixation process. Therefore, irregular verbs should be better preserved than regular/mixed verbs in both simple past and past participle.

Alternatively, mixed verbs could be represented holistically. As suggested by Westermann in his commentary to Clahsen (1999, p. 1024), *-t*, and *-te* respectively could be part of the lexical entry, similarly to the claim for irregular participle ending *-n* (Wunderlich, 1997). Thus, if mixed verbs are stored holistically, they should not be affected by a disruption in inflectional processes and pattern with irregulars in being better preserved than regulars.

Methodology

Participants

A group of nine German agrammatic speakers participated in the study (mean age: 53.8; age range: 36–71; see Appendix A, Table A1 for individual information). All participants had been previously diagnosed with Broca’s aphasia by a speech and

language therapist using the Aachener Aphasia Test (AAT; Huber, Poeck, Weniger, & Willmes, 1983). All participants had been classified as individuals with agrammatism on the basis of their spontaneous speech. Participants gave their informed consent to participate in the study. A group of seven non-brain-damaged speakers of German was tested as a control group. They were matched at the group level on age and years of formal education, were all German native speakers and had a medical history free of any records of neurological diseases and learning impairments (for individual information see Appendix A, Table A2).

Material

Regular, irregular and mixed verb classes comprised eight experimental items each (24 verbs in total; cf. Appendix B, Table B1). These verbs were grouped into twelve pairs such that they could take the same object (e.g., 'to bring/to pack the package'). The first verb of each pair served as stimulus item while the second verb was the one that had to be elicited (see description of the procedure). All verbs were equally often used as stimulus and target item across all conditions. Therefore, the participants were presented with both verbs throughout the test (i.e., *think-write* and *write-think*). The order of the items was pseudo-randomized. For SOV languages like German and Dutch, it has been shown that it is significantly easier for agrammatic individuals to complete an embedded clause than completing a matrix clause in which time reference interacts with verb movement (Bastiaanse, Hugen, Kos, & Van Zonneveld, 2002). Therefore, verbs were elicited in a sentence completion task in which the critical verb was embedded in a subordinate clause so that it appeared in its base position (cf. Test for Assessment of Reference of Time: TART, Bastiaanse, Jonkers, & Thompson, 2008). The stimulus and target sentence corresponded to colored photographs that were arranged on two sides of a page in horizontal format (see Figure 2). The infinitive forms of both verbs were printed in lower case font centered above each photograph. Different photographs were used to elicit present tense, simple past and present perfect forms (auxiliary + past participle) in a total of 72 trials.

Regular and mixed verbs are identical in number of syllables in all time frames. Irregular verbs resemble regular and mixed verbs in present tense. Irregular simple past forms have fewer syllables than regular and mixed verbs. Irregular past participles contain more syllables than regulars and irregulars (see Appendix B, Table B2).

Nickels & Howard (2004) found that the number of phonemes is a decisive predictor of spoken word production in apraxic and aphasic patients. Therefore, the average number of phonemes was controlled. The average number of phonemes was not different among the three verb types in present tense. There is, however,



Figure 2. Example of the stimulus presentation ('to change the diaper', 'to feed').

a difference in simple past such that irregular verbs are on average shorter than regulars and mixed verbs. In past participle, irregular verbs are on average longer than regulars and mixed verbs. Regular and mixed verbs do not differ across time frames (see Appendix B, Table B3 for means). In addition to syllable number and number of phonemes, verbs were selected in such a way that the number of initial, medial and final consonant clusters was similar (see Appendix B, Table B4).

In summary, these phonological matching criteria motivate the assumption that regular and mixed verbs are similar in their phonological complexity. Irregular verbs are simpler than regular/mixed verbs in simple past and they are more complex than regular/mixed verbs in present perfect tense. Note that it is exactly this difference in phonological complexity between regular/mixed and irregular verbs, which is part of the predictions described in the previous section.

Verbs were also matched for (log) lemma frequency and (log) word form frequency using the CELEX database for both spoken and written samples (Baayen, Piepenbrock, & Rijn, 1993). All verb classes contained frequent and infrequent items. Infrequent word forms had a log frequency of < 1.97 . Frequent items were > 2.55 (see Appendix B, Table B5).

The materials were tested in a pilot study with four non-brain-damaged speakers of German (different from the control group) in order to ensure that the test was appropriate. The performance was at ceiling.

Procedure

The experimental items were presented on a computer screen using a Powerpoint presentation. The participants were seated in front of the computer screen and the experimenter made sure that all items were well visible to the participant. Six practice items were part of the instructions. The instructions were read to the participant who was told to look at the verbs as well as the respective photographs and to listen carefully to the (stimulus) sentence produced by the experimenter. The participant was then told to listen to the (target) sentence which the experimenter continued to produce. The participant was asked to complete the target sentence, following the pattern of the stimulus sentence. The experimenter started to point to the picture and read out the respective verb in the infinitive, for example:

- (1) *Das ist das Foto für 'wickeln'.* *Und das ist das Foto für 'füttern'*
this is the photo for 'change the diaper'. And this is the photo for 'to feed'
- (2) *Für dieses Foto könnte ich sagen,*
for this photo could I say,
'For this photo I could say'

Pointing to the first photograph, the experimenter continued to say:

- (3) *Hier ist die Frau, die das Baby wickelt.*
here is the woman who the baby changes.
'Here is the woman who changes the baby'

Then, the experimenter encouraged the participant to complete the second half of the target sentence by pointing to the second picture saying:

- (4) *Hier ist die Frau, die das Baby _____.*
here is the woman who the baby _____.
'Here is the woman who_____ the baby'

After the practice phase, the experimental trials were presented one by one. If requested, the stimulus sentence was repeated once. Self-corrections were allowed within a time period of twenty seconds. The participants' responses were audio recorded, transcribed and scored.

Scoring

The participants' responses were scored both quantitatively and qualitatively. For the quantitative analysis, the responses were scored as either correct or incorrect. As the research question focused on morphological processes, the quantitative analysis was restricted to the lexical verb. Apart from the target form, substitutions

were accepted as correct if they were semantically plausible, morpho-syntactically correct, corresponded to the target time reference frame and belonged to the same verb class as the target verb. For example, if the mixed verb *weiß* ('knows') was produced instead of mixed *kennt* ('knows'), the response was scored as a correct answer. Phonological errors were ignored if only one phoneme was substituted, the substitution did not affect the inflectional endings or a stem vowel change and if the target verb was still recognizable as such. For example, instead of *schneidet* ('cuts') participant R.R. produced *schleidet* which was scored as correct. Overall, the number of phonological errors and acceptable substitutions was low (0.31% and 0.62% of all trials).

Data analysis

To test the influence of verb regularity and time reference on the accuracy of the sentence completion in agrammatic participants we used a linear mixed model (Bates, 2005). This model had accuracy as the dependent variable (1=correct, 0=incorrect) and a binomial link function. Regularity and time reference were fixed effects and were both coded as Helmert contrasts: in a first contrast, we compared regular verbs with mixed and irregular verbs taken together and in a second contrast mixed verbs with irregular verbs. Similarly, we first compared present tense verb forms with participles and simple past verb forms taken together. In a second contrast, participles and simple past verb forms were compared. We also added a fixed effect term for the interaction of regularity and time reference. The random effect structure included random intercepts for participants and verbs and random slopes for all fixed effects that were measured repeatedly in participants or verbs: for participants, there were random slopes for regularity, time reference, and for their interaction. For verbs, there were random slopes for time reference only because regularity was constant for each verb. The correlations of these random effects were not estimated. For calculating the fit of the mixed model, we used the package lme4 (Bates) for the R system (R Development Core Team, 2009).

Results

Quantitative analysis

Figure 3 shows the mean accuracy of sentence completion for regular, mixed, and irregular verbs and for present tense verb forms, participles, and simple past verb forms. The means of agrammatic participants are shown in black and the means

of the control participants in grey.¹ The intervals are 95% confidence intervals calculated with the Clopper-Pearson exact method (Clopper & Pearson, 1934).

Agrammatic patients produced present tense successfully more often than participles and simple past forms. This effect was highly significant ($\beta=0.577$, $SE=0.152$, $z=3.8$). Moreover, participles were completed successfully more often than past tense verb forms. However, this effect was only marginally significant ($\beta=0.29$, $SE=0.169$, $z=1.746$).

Agrammatic participants produced regular verbs significantly more often successfully than mixed and irregular verbs ($\beta=0.32$, $SE=0.13$, $z=2.445$). There was no difference between mixed and irregular verbs ($\beta=0.075$, $SE=0.191$, $z=0.393$). The interaction between regularity and time reference was also not significant. See Figure 4 for a plot of the coefficients and approximate 95% confidence intervals and Appendix C, Table C1 for statistical information.

We also computed a model with the same specifications for the control participants and found no effects of regularity and tense and no interaction of these factors.

All of the items were used as stimulus and target across all conditions. To examine whether participants are more accurate on items which they have seen as stimulus before, a paired t-test was calculated. Items were coded as 'seen as stimulus first' (yes=1) or 'not seen as stimulus first' (no=0). We found no difference between items that had been seen before as stimulus (accuracy 33.02%) as compared to those that had not been seen before (accuracy 31.79 %), $t(8)=-1.5918$,

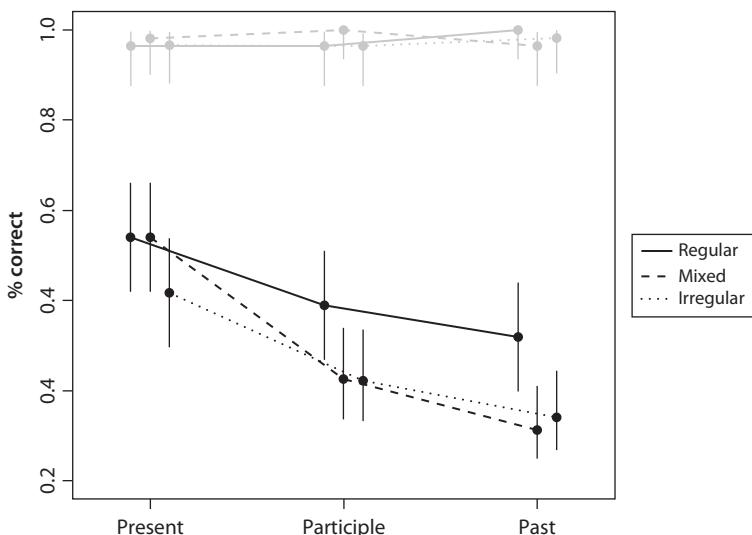


Figure 3. Mean accuracies for regular, mixed and irregular verbs in present, past participle and simple past.

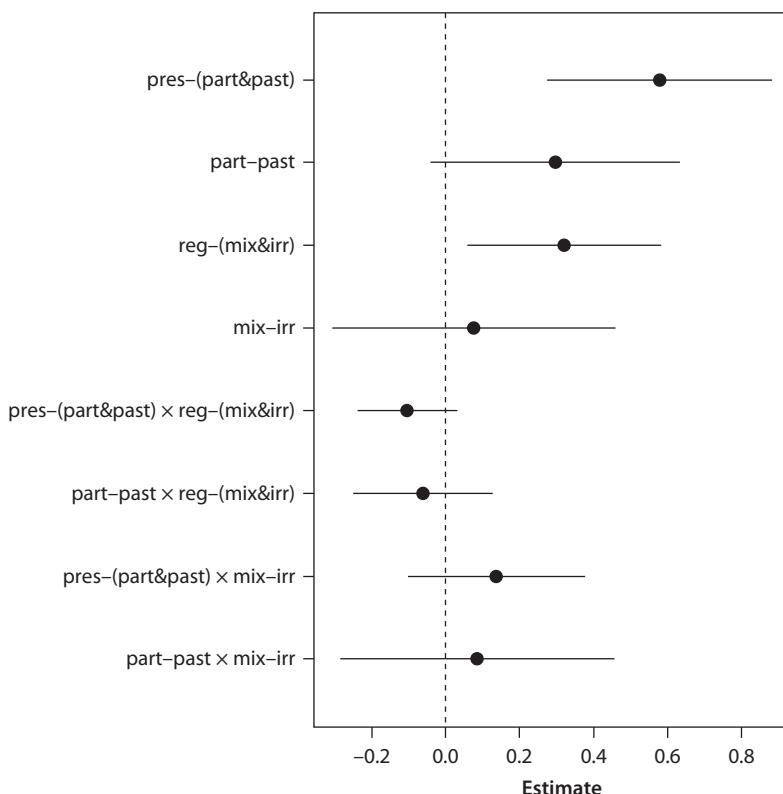


Figure 4. Estimated coefficients for a linear mixed model that tested the influence of verb regularity and tense on the successfulness of a sentence completion. The intervals are 95% confidence intervals and were computed by multiplying the standard errors of the estimates by two and by adding and subtracting these values from the estimates to get the end points of the intervals. (present tense = ‘pres’, simple past = ‘past’, past participle = ‘part’; regular verbs = ‘reg’, irregular verbs = ‘irr’, mixed verbs = ‘mix’).

$p=0.1501$. We can thus safely assume that the order of presentation of the stimuli did not influence the results.

Word form frequency of test items. Figure 5 shows the performance of the agrammatic participants for different values of time reference and regularity with high- and low-frequency verb forms presented separately. Irregular verbs were processed more accurately when they were high frequent rather than low frequent. For mixed verbs, an effect of frequency is only visible for present tense verb forms. However, as will be discussed later, present tense is confounded by diverging regularity patterns in most of the mixed verbs and half of the irregulars. Therefore, present tense was not considered in the analysis of frequency reported below.

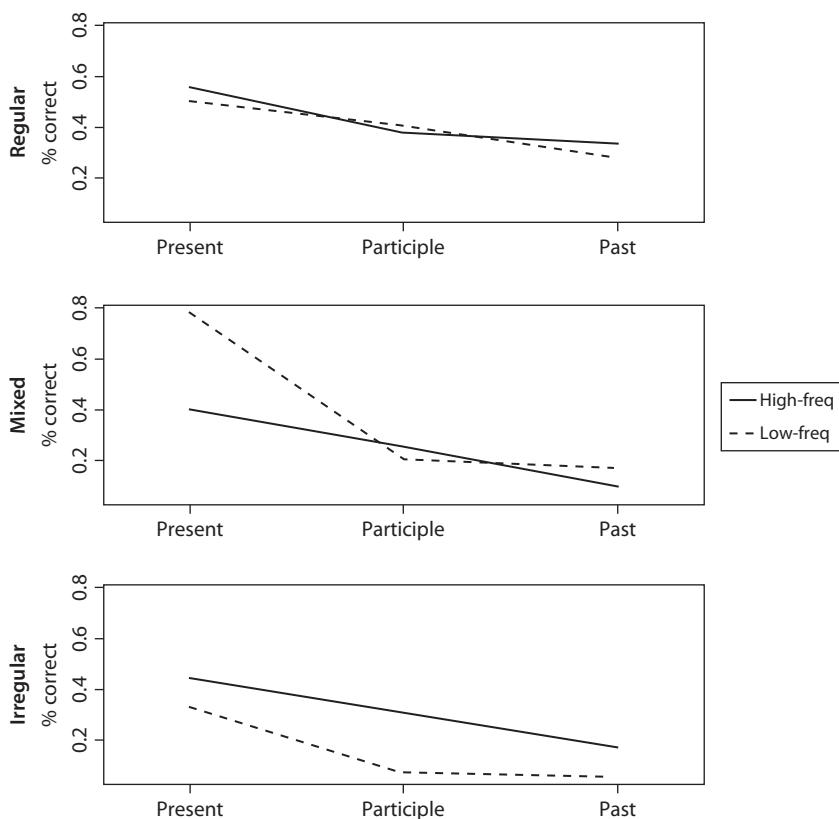


Figure 5. Mean accuracy by frequency in percent.

We calculated a linear mixed model similar to that reported above (see Appendix C, Table C2 for statistical information). However, this model did not have a term for the interaction of time reference and regularity because there was no evidence for such an interaction. Instead, we added frequency as a fixed effect and a term for the interaction of regularity and frequency. Frequency was a dichotomous variable; high frequency was coded as 1, low frequency as -1.

The contrast coding for regularity was different from the previous model because we wanted to compare regular and mixed verbs together with irregular verbs. Therefore, we defined a Helmert contrast for regularity that had a contrast for the respective comparison and another contrast comparing regular and mixed verbs to each other. Because of the problematic status of mixed verbs in the present tense mentioned above, we only included data from trials in which a participle or a simple past form was required. The model had random intercepts for participants and verbs. Initially, the model also had random slopes for frequency, regularity, and time reference for participants and random slopes for the effect of time

reference for verbs.² This model did not converge properly indicating that there was insufficient data to estimate all parameters. Therefore, we iteratively removed those random effects that explained the least variance until the model converged. This resulted in the removal of random slopes for the effects of frequency and regularity for participants. See Figure 6 for a plot of the estimated coefficients and approximate 95% confidence intervals.

The estimates of this model are consistent with the results of the model reported previously: participles were completed successfully more often than simple past forms but, again, this effect was only marginally significant ($\beta=0.31$, $SE=0.162$, $z=1.913$). Regular verbs and mixed verbs taken together were produced successfully significantly more often than irregular verbs ($\beta=0.34$, $SE=0.147$, $z=2.318$)

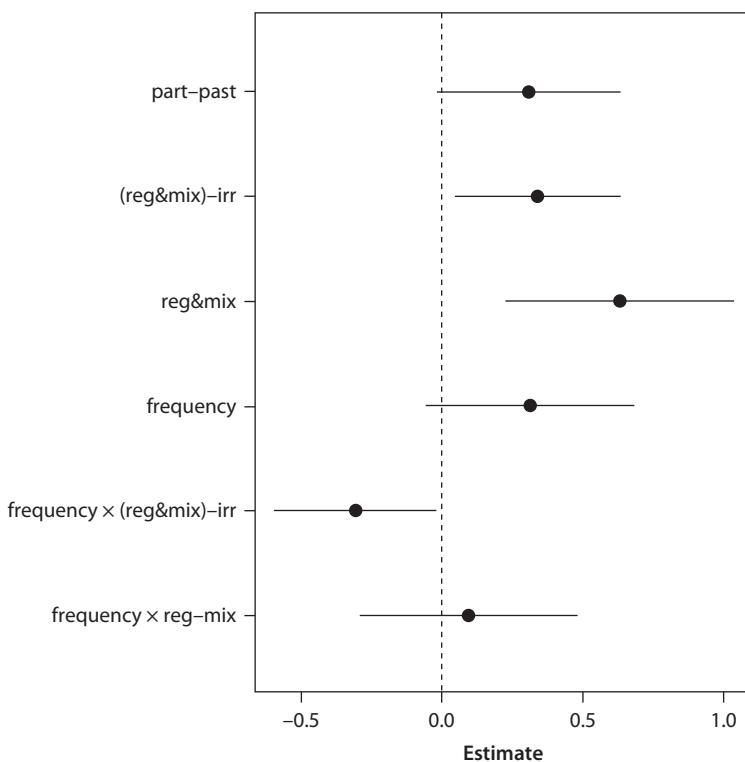


Figure 6. Estimated coefficients for a linear mixed model that tested the influence of verb regularity, tense, and frequency of the verb form on the correctness scores in sentence completion. The intervals are 95% confidence intervals and were computed by multiplying the standard errors of the estimates by two and by adding and subtracting these values from the estimates to get the endpoints of the intervals. (present tense = 'pres', simple past = 'past', past participle = 'part'; regular verbs = 'reg', irregular verbs = 'irr', mixed verbs = 'mix').

and regular verbs were processed significantly more accurately than mixed verbs ($\beta=0.633$, $SE=0.202$, $z=3.128$). Additionally, there was a marginally significant main effect of frequency: high frequency verb forms were completed correctly more often than low frequency verb forms ($\beta=0.314$, $SE=0.186$, $z=1.681$). Finally, as suggested by Figure 5, there was a significant interaction of frequency and regularity: when frequency was high, the difference between both regular and mixed verbs and irregular verbs was smaller ($\beta=-.306$, $SE=0.144$, $z=-2.121$).

We also fit an analogous model for control participants. Again there were no significant effects. This is not surprising because control participants performed at ceiling.

Qualitative analysis

In a post hoc error analysis, the following error types were identified: infinitive responses, target time frame violations, regularization errors, nil responses, repetition errors, phonological errors and multiple errors. Verbs which were not inflected but produced in the infinitive (without an auxiliary) were scored as pure infinitive responses. Note that in German, the infinitive does not consist of the stem alone rather than stem + 'en' (e.g. *pack-en* 'to pack'). *Target time frame violations* are errors which are morpho-syntactically correct and do establish some kind of time reference but deviate from the target time frame. This type of error can occur with or without a time frame violation. For example, if the target verb is in simple past but the response is a past participle, the response differs from the target time frame, but does not violate time reference to the past. Furthermore, constructions consisting of 'infinitive + auxiliary', such as *nehmen kann* ('take can'), establish a time reference and are a well-formed completion of the target sentence but not in the intended form. Therefore, these responses were also classified as time frame violations.

A response was classified as *regularization error* if a regular inflectional ending was applied to an irregular or mixed stem while the participant failed to realize the stem change, for example, as in *bergte* (infinitive *bergen*) for *barg* ('rescued'). Responses which were identical to the stimulus form were coded as *repetition error*. For example, if the participants heard *schreibt* ('writes') as stimulus in order to produce the target form *denkt* ('thinks') but responded with the form *schreibt*. Omission of inflectional affixes occurred exclusively for the prefix *ge-*, for example, if *rannt* was produced instead of *gerannt* ('ran'). Since *ge-* is phonologically conditioned (Clahsen, 1999; Wiese, 1996), this type of error was classified as phonological error. If no answer was given, the response was scored as *nil response*. Finally, if a response was characterized by several errors, it was classified as a *multiple error*. Only few responses could not be classified according to these error categories

Table 3. Error types and occurrence in % in relation to all trials listed per verb class for all time frames taken together

	Regular (n _{error} =126/216)	Irregular (n _{error} =159/215)	Mixed (n _{error} =151/214)	Total (n _{error} =436/645)
Nil response	2.31	2.33	3.27	2.64
Regularization	–	5.58	2.8	2.79
Repetition	0.93	2.33	1.4	1.55
Phonological errors	0	0.47	1.4	0.62
Pure infinitive	12	17.7	14	14.6
+ time frame violation	23.6	20.5	22.9	22.3
- time frame violation	10.6	7.44	6.07	8.06
(Total target time frame errors)	(34.2)	(27.9)	(29)	(30.4)
Other errors	8.79	17.7	18.7	15

(5.76%). Those errors were labeled as unclassified errors and were put into the error category ‘other errors’ together with multiple errors.

The total number of errors made by the group of agrammatic speakers was 436 out of 645 trials. The distribution of error categories can be seen in Table 3. Target time frame errors which are morpho-syntactically correct but deviate from the target time frame can occur with or without a violation of the target time reference. 22.3% of all trials were target time frame errors with a violation of time reference. 8.06% of all trials were target time frame errors without time reference violation.

Again, pure infinitive responses and target time frame errors (both with and without time reference violation) were the most frequent errors. In line with the assumption that “whatever error form the aphasic speaker uses is simpler for her *at the moment* than the correct target form” (Menn, 2008, p. 375) an analysis was done to see which forms were used to substitute a target form. The percentages were calculated in reference to all trials (see Figure 7).

Discussion

The key findings in the current study were that agrammatic participants performed better on regular verbs compared to irregular verbs. Mixed verbs were equally difficult as irregular verbs. Simple past and past participle were significantly more difficult than present tense. Moreover, a full form frequency effect was found for irregular but not for regular and mixed verbs. Pure infinitive responses and errors

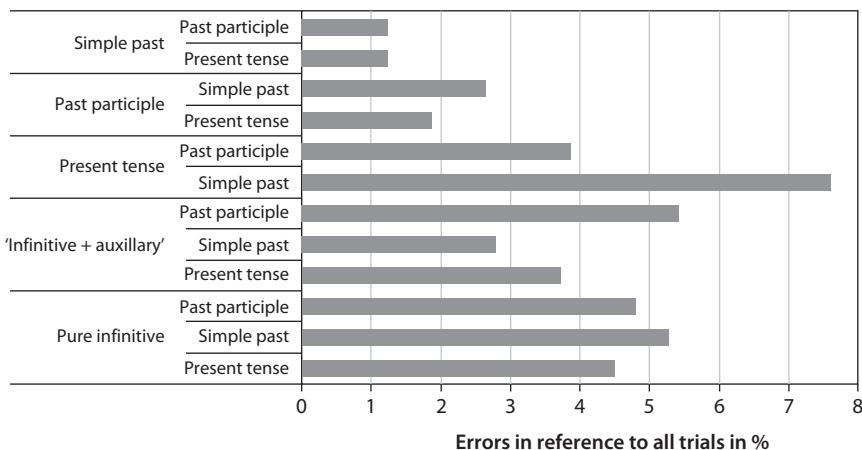


Figure 7. Percentages of the types of target time frame violations and pure infinitives. The first column shows the form used to substitute the target form which is shown in the second column.

involving time reference were the most common error types. These results will be discussed in the following section.

Regular, irregular and mixed verbs in german agrammatic language production

The Single Mechanism approach and its explanation of regular/irregular dissociations in terms of a phonological deficit (Bird et al., 2003) enabled fine-grained predictions for the present materials. The pattern in the data, however, does not support the predictions. In simple past and past participle, mixed verbs pair with irregulars instead of regulars. As predicted, no difference in present tense between verb classes was found. Yet, this may be attributable to confounding regularity patterns in present tense which will be discussed in the section ‘Regularity in present tense’. Since the predictions did not comply with the results in the critical conditions in simple past and past participle, no influence of phonological complexity on the agrammatic participants’ performance across verb classes was measurable.

The results partially support the DMM and the DP model in that regulars and irregulars dissociate (Pinker & Ullman, 2002; Ullman, 2004), but they also differ because the model predicts that agrammatic speakers “have more trouble with regular than irregular morphology” (Ullman, 2004, p. 252). This claim is not supported by our data.

The results replicate the quantitative findings in Penke & Westermann (2006) and support the argument that a selective deficit of regular inflectional morphology is not a defining feature of Broca’s aphasia cross-linguistically. Yet, in their

study 81% of all errors consisted of regularization errors while in the current study merely 2.79% of all responses (that is, 5.83% of all errors) were regularization errors. Moreover, the accuracy scores in Penke & Westermann for regulars were much higher compared to our results. One reason for this may be that the participants in our study were more severely impaired. It may also be the case that in the previous study only participles were elicited. In the current study, finite verbs were elicited in addition to participles and the time reference frame was varied. Therefore, the participants had to do more computation and task switching. Yet, this was constant across conditions.

Penke & Westermann (2006) point out that in languages with rich inflectional morphology, such as German, inflectional endings are less likely to be omitted because they are syntactically more relevant. This is also consistent with errors found in the current study. German agrammatic speakers hardly ever omitted inflectional morphemes (0.62%). The majority of errors were either pure infinitive responses (14.6% of all trials) or target time frame errors (30.4% of all trials). However, a high number of infinitive responses is consistent with previous reports of German agrammatic production (Penke, 1998).

Regularity in present tense

Verb class membership in German is not always consistent in present tense for irregular and mixed verbs. By convention, assignment to a particular verb class has been done on the basis of infinitive, simple past and past participle forms alone (but see Trompelt, 2010 for an alternative classification). This classification disregards the fact that present tense irregulars and mixed verbs do carry a regular affix (e.g., *brenn-t* ‘burns’). In addition, irregular present tense forms may or may not change the stem (e.g. *liegen-liegt* ‘to lay-lays’, *nehmen-nimmt* ‘to take-takes’).

It follows, that the results for irregular and mixed verbs in present tense may be affected by these inconsistencies in regularity. In Figure 3, a marked effect of regularity in simple past and past participle is evident while in present tense the accuracy scores for regular and mixed verbs do not show a significant difference. Irregulars were significantly less often correct than regular and mixed verbs, yet, they are not as poor as in simple past and past participle.

The reason why we do not see the same effect in present tense compared to simple past and past participle is because most of mixed present tense verbs ($n_{\text{mixed}} = 6/8$) and half of irregular present tense verbs ($n_{\text{irregular}} = 4/8$) are formed in a regular manner. That is, no stem change is involved and regular affixation applies.

Since regularity in present tense was not controlled for, no statistical analysis was performed on the data. However, the proportions indicate that irregular and mixed verbs that are affixed regularly in present tense are answered correctly in

55.6% of the time. Irregular and mixed verbs which involve a stem change were answered correctly in only 25.9% of the cases. In summary, these findings indicate that it may be the stem change in irregular and mixed verbs which causes trouble in agrammatic production and call for further investigation of regularity patterns in present tense.

Mixed verbs in agrammatic language production

The DMM and the DP hypothesis predict that idiosyncrasies are processed differently from rule based morphology. Thus, mixed verbs would be stored in the mental lexicon either as full forms or structured lexical entries on which affixation operates. If stored as structured lexical entries, mixed verbs should pattern with regular verbs in all time frames alike and be more impaired than irregular past participle and simple past forms. If mixed verbs are stored as full forms, they should pair with irregulars in past participle and simple past and be better preserved than regulars. However, these predictions only apply if an advantage of irregular over regular inflection is indeed characteristic of Broca's aphasia across languages. As discussed above, mixed verbs indeed pair with irregulars and not with regulars, but the direction of the effect is opposite. However, since irregular and mixed verbs appear to be more severely impaired than regular verbs, no conclusions can be drawn as to whether mixed verbs are represented holistically or as structured lexical entries from accuracy scores alone.

The frequency effect found for irregular verbs can be accounted for by both the DMM and the Single Mechanism model (Pinker & Prince, 1994, p. 327; Daugherty & Seidenberg, 1992). For agammatism individuals, full form frequency effects have been observed by Penke & Westermann (2006). In the DMM assuming holistic representations of mixed verbs and *-t* and *-te* being part of the lexical entry, such an effect is predicted. For mixed verbs, the Single Mechanism approach does not predict a frequency effect, and in fact, no frequency effect was found for mixed verbs. Since this effect was found in a post-hoc analysis, replication in a follow-up study is necessary.³

Time reference to the present and past

Reference to the past is impaired across all verb types. Time reference to the present appears to be significantly better than both simple past and past participle for all verb types. However, as discussed in the previous section, regularity in present tense was not controlled for irregular and mixed verbs. Thus, regularity in present tense and its interaction with time reference call for further investigation.

The current findings are in line with results found for agrammatic speakers in a wide range of languages (Abuom & Bastiaanse, 2012; Bastiaanse et al., 2011) and support the idea that time reference to the past is impaired in speakers with agrammatic aphasia. The result is not in line with Clahsen & Ali (2009) who did not find a difference between present tense and simple past. As pointed out by Bastiaanse et al. (2011), the reason for this could be the nature of their task as it did not involve pure language production.

Time reference appears to be a general issue because a great number of all trials involved the violation of target time reference (30.4%) or pure infinitive responses (14.6%) in which no time reference was made at all. The analysis of the nature of the time reference frame errors revealed an interesting pattern that was similar to the hierarchy for the production of verb forms proposed by Bastiaanse (2008). In her study, finite verbs were easier to produce than non-finite verbs, and simple past forms were more difficult than present tense (all in base position). Past participles should be easier to produce than present tense forms according to Bastiaanse's hierarchy (2008) because they are non-finite. This predicts that agrammatic participants substitute non-finite past participles for a simple past target more often than finite present tense. However, this would imply that reference to the past has to be established which is difficult for agrammatic participants. Thus, this explains why present tense forms are used much more frequently to substitute a target form: reference to the past is more difficult for agrammatic speakers than reference to the present tense (Bastiaanse et al., 2011).

Conclusion

The purpose of the current study was to test claims about the processing and representation of inflectional morphology by testing mixed verbs and the regular-irregular distinction in German agrammatic aphasia under consideration of time reference. Investigating minor lexical patterns such as mixed verbs and testing those with agrammatic individuals is essential to finding new evidence in the debate on how inflectional morphology is represented and processed in the brain.

To the best of our knowledge, this study is the first one to test mixed verbs in German agrammatic aphasia. It showed that mixed verbs were equally impaired as irregular verbs. However, the frequency effects for irregular but not mixed verbs underscore that mixed verbs need to be studied further.

The current results confirmed patterns previously found for participles in German agrammatic aphasia, that is, significantly worse performance on irregular verbs compared to regulars (Penke & Westermann, 2006). Our study shows that this

dissociation also holds for German simple past tense. Likewise, the results indicate that regularity in present tense deserves more attention because accuracy scores appear to go up for irregular and mixed verbs as soon as no stem change is involved.

The observed effect is opposite of what is predicted by the DMM and DP model and it supports that an impairment of regular inflection is not characteristic of German agrammatic aphasia (Penke & Westermann, 2006).

Moreover, the claim that language specific differences can account for cross-linguistic agrammatic data (Penke & Westermann, 2006) is supported by the observed error patterns. There were no omission errors, except for the very rare omission of phonologically conditioned *ge-*, which was, thus, coded as phonological error. This suggests that inflectional affixes are grammatically more relevant in German and, therefore, are omitted less frequently.

The correctness scores did not reflect an influence of phonological complexity. We are not suggesting that phonological complexity did not have any influence at all on the participant's performance but it is not likely that this is the solitary factor underlying the dissociations between regular and irregular inflection in previous studies. Finally, this study provides evidence that reference to the past, both through simple past and past participle is impaired.

Author note

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Notes

1. Three data point are missing from participant C.R. due to an experimenter error.
2. Some verbs had verb forms in different frequency classes but this appeared only rarely. Therefore, frequency was effectively constant within verbs and adding random slopes for frequency did not seem sensible.
3. Note that alternative explanations for frequency effects (of the lack thereof) in lexical decision have been proposed (Baayen, 2010; Baayen, Levelt, Schreuder, & Ernestus, 2008; Taft, 2004) and need to be taken into account when further investigating word form frequency in mixed verbs.

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Appendix A

Table A1. Demographic data of agrammatic individuals

Participant	Sex	Y. p. o.	Age	Type of Aphasia (AAT)	Etiology/Localization	Handedness	Occupation	Ed
C.R.	m	7	46	Broca's aphasia	left fronto-parietal CVA (hemorrhage)	r	restaurant proprietor	13
S.S.	f	3;3	45	Broca's aphasia	left temporo-parietal CVA (hemorrhage)	r	assistant tax consultant	13
K.C.	f	2;2	36	Broca's aphasia	left CVA (hemorrhage)/ arteria cerebri media	r	geriatric nurse	13

Table A1. (continued)

Participant	Sex	Y. p. o.	Age	Type of Aphasia (AAT)	Etiology/ Localization	Handedness	Occupation	Ed
H.G.	m	14;7	58	Broca's aphasia	left CVA	r	concrete tester	15
R.R.	f	14	57	Broca's aphasia	left CVA	r	accountant	13
U.W.	m	10;7	71	Broca's aphasia	left CVA	r	architect	15
W.E.	m	14	70	Broca's aphasia	left CVA/ infarction arteria cerebri media	r	caretaker	10
U.B.	m	3;9	51	Broca's aphasia	left CVA	r	electrician	12
C.E.	m	2;10	50	Broca's aphasia	left CVA/ infarction arteria cerebri media	r	road builder	13

Note. Y.p.o. = Years post onset; Sex: m = male, f = female; Age = age at testing; AAT = *Aachener Aphasia Test* (Huber et al., 1983); CVA = cerebrovascular accident; Handedness: r = right handed; Ed = Years of formal education.

Table A2. Demographic data of the matched control speakers

Participant	Sex	Age at testing	Handedness	Occupation	Ed
S.U.	f	46	r	police officer	13
I.T.	f	45	r	accountant	13
J.H.	f	35	r	manager	14
G.K.	m	59	r	engineer	15
D.H.	m	56	r	works council	13
U.I.	m	70	r	economist (retired)	16
B.U.	m	70	r	telecommunication technician (retired)	10

Note. Sex: m = male, f = female; Handedness: r = right handed; Ed = Years of formal education

Appendix B

Table B1. German verb pairs, their english translation and verb class membership

Item	German verb pairs and verb class membership	English translation	
	<i>wickeln</i> (regular) <i>füttern</i> (regular)	to change the diaper	to feed
(1)	<i>wissen</i> (mixed) <i>nennen</i> (mixed)	to know	to name
(2)	<i>spielen</i> (irregular) <i>sprechen</i> (irregular)	to play	to speak
(3)	<i>denken</i> (mixed) <i>schreiben</i> (irregular)	to think	to write
(4)	<i>bergen</i> (irregular) <i>kennen</i> (mixed)	to rescue	to know
(5)	<i>nehmen</i> (irregular) <i>brauchen</i> (regular)	to take	to need
(6)	<i>suchen</i> (regular) <i>brennen</i> (mixed)	to look for; to search	to brand
(7)	<i>liegen</i> (irregular) <i>sitzen</i> (irregular)	to lie	to sit
(8)	<i>bringen</i> (mixed) <i>packen</i> (regular)	to bring	to pack
(9)	<i>zeigen</i> (regular) <i>rennen</i> (mixed)	to point	to run
(10)	<i>schneiden</i> (irregular) <i>halten</i> (irregular)	to cut	to hold
(11)	<i>mögen</i> (mixed) <i>küssen</i> (regular)	to like	to kiss
(12)	<i>stellen</i> (regular) <i>hören</i> (regular)	to apprehend	to hear

Table B2. Number of syllables per condition

	Regular	Irregular	Mixed
Present tense	1	1	1
Simple past/3sg	2	1	2
Past participle	2	3	2

Table B3. Mean number of phonemes and standard error per condition

	Regular		Irregular		Mixed	
	M	SE	M	SE	M	SE
Present tense	4.38	0.183	4.88	0.295	4.13	0.295
Simple past/3sg	5.38	0.183	3.75	0.25	5.25	0.164
Past participle	6.38	0.183	7.75	0.25	6.25	0.164

Table B4. CV-structure

	Regular	Irregular	Mixed
Present tense	1	1	1
Simple past/3sg	2	1	2
Past participle	2	3	2

Table B5. Mean word form frequency and standard error per condition

	Regular		Irregular		Mixed	
	M	SE	M	SE	M	SE
Present tense	2.48	0.23	2.51	0.23	2.33	0.19
Simple past/3sg	2.46	0.13	2.53	0.23	2.44	0.15
Past participle	2.31	0.22	2.23	0.20	1.77	0.33

Appendix C**Table C1.** Summary of the linear mixed model of the accuracy on regular, irregular and mixed verbs in present tense, simple past and past participle

	coefficient	SE	z-value
(Intercept)	-1.13166	0.38222	-2.961
pres — (part & past)	0.56388	0.14943	3.773
part — past	0.28023	0.16449	1.704
regular — (mixed & irregular)	0.31827	0.10026	3.175
mixed — irregular	0.07020	0.18338	0.383
pres — part & past × regular — mixed & irregular	0.10439	0.06482	-1.610
part-past × regular — mixed & irregular	0.05517	0.09217	-0.599
pres-part & past × mixed — irregular	0.13654	0.11667	1.170
part-past × mixed-irregular	0.08302	0.18196	0.456

(pres = present tense; past = simple past; part = past participle)

Table C2. Summary of the linear mixed model of accuracy by frequency

	coefficient	SE	z-value
(Intercept)	-1.83006	0.46537	-3.932
part — past	0.30942	0.16175	1.913
(regular & mixed) — irregular	0.34011	0.14670	2.318
regular — mixed	0.63315	0.20241	3.128
high — low	0.31350	0.18648	1.681
(regular & mixed) — irregular × high — low	-0.30583	0.14416	-2.121
regular — mixed × high-low	0.09544	0.19536	0.489

(pres = present tense; past = simple past; part = past participle)

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