Accessing morphosyntactic information is preserved at old age, except for irregulars

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The current study examined morphological priming in older individuals using two complex phenomena of German inflection. Study 1 examined inflected adjectives which encode multiple morphosyntactic features using regular affixes. Study 2 targeted inflected verb forms which also encode multiple features, but in this case using idiosyncratic stem variants. Study 1 revealed priming effects indicating efficient access of morphosyntactic features from inflected word forms with regular affixes. Study 2 showed that the same individuals were less efficient at accessing morphosyntactic features from marked stems. We argue that this contrast reflects age-related memory decline, which affects feature access from (lexically conditioned) stem variants more than feature access from lexically unconditioned regular forms.

Keywords: morphological processing, morphosyntactic features, affixation, allomorphy, memory

Over the past 100 years, the average human life expectancy has nearly doubled (Riley, 2005). These days, reaching an age of 70 years is considered normal in many industrialized countries, while it was an anomaly just a few generations ago. This increase in longevity calls for research on cognitive functioning in older people. Research on the development of cognition across the lifespan has found a decline in a number of processes. Older people show a decrease in general processing speed (see Verhaeghen and Salthouse, 1997, for a meta-analysis), executive functioning (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007; Treitz, Heyder, & Daum, 2007; Verhaeghen & Cerella, 2002; Wecker, Kramer, Wisniewski, Delis, & Kaplan, 2000; but see Verhaeghen, 2011), working memory (Dobbs & Rule, 1989; Foos, 1989; Salthouse, 1994; Wingfield, Stine, Lahar, & Aberdeen, 1988), and declarative memory (Park, Lautenschlager, Hedden, Davidson, Smith, & Smith, 2002; Singer, Verhaeghen, Ghisletta, Lindenberger, & Baltes, 2003; Verhaeghen, Marcoen, & Goossens, 1993). With respect to language performance, linguistic tasks tapping

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lexical access have been found to be particularly affected by aging. Older people get slower and, at times, less accurate at picture naming (see Mortensen, Meyer, and Humphreys, 2006, for a review) and lexical-decision tasks (Allen, Madden, & Crozier, 1991; Bowles & Poon, 1981; Newman & German, 2005). They also show an increase in tip-of-tongue events, both spontaneous and induced ones (see Burke & Shafto, 2004, for a review).

Considerably less is known about grammar and grammatical processing in older speakers, and the existing evidence is rather mixed. Some studies report preserved grammatical processing, for instance in sentence-monitoring tasks (Davis, Zhuang, Wright, & Tyler, 2014; Tyler, Shafto, Randall, Wright, Marslen-Wilson, & Stamatakis, 2010) or during the processing of regular compounds (Duñabeitia, Marin, Avilés, Perea, & Carreiras, 2009). Other studies reported difficulties in older speakers' grammatical processing; these findings include difficulties in extracting roots from inflected or derived words in Hebrew (Kavé & Levy, 2005), the processing of left-branching sentences in English (Kynette & Kemper, 1986), the computation of pronoun-antecedent dependencies (Light & Caps, 1986) or ambiguity resolution (Kemtes & Kemper, 1997), and an enhanced susceptibility to agreement attraction errors (Reifegerste, Hauer, & Felser, 2017). For morphological processing, Clahsen and Reifegerste (2017) obtained a dissociation between regular and irregular inflection in two experiments. In a morphological priming task testing German participle forms, older speakers showed efficient priming for regular (-*t*) participles, but not for irregular (-*n*) participles, where previous studies with younger adults had yielded priming effects for both types of participles. Clahsen and Reifegerste attributed this contrast to the increased involvement of memory-based retrieval processes for irregular verb forms. Further evidence comes from an elicited production task in which older speakers' performance in producing irregular German participles was found to be modulated by verbal memory. Specifically, older participants with lower verbal-memory scores showed weaker frequency effects for irregular forms than participants with higher scores did. The authors did not find such a modulation for regular participles. They argued that a decline in memory – arguably one of the hallmarks even of healthy aging – leads to weaker links between lexical entries stored in the mental lexicon (including a stem and its irregular participle form), which in turn results in smaller benefits from threshold-lowering properties of words, such as form frequency. As regular participle formation is lexically unconditioned (e.g., Clahsen, 1999), their processing is less affected by memory limitations.

In the present paper, we will investigate further how older people process inflected word forms, focusing on the comparison between morphological computation and lexical access during online language comprehension. To this end, we examined two inflectional processes of German, (i) attributive adjective forms that are marked for gender, case, and number (e.g., *müdes* – *müdem* 'tired') and (ii) present-tense forms of (so-called strong) verbs such as *wirft* – *werfen* 'throws – (to) throw' that have lexically conditioned marked stems with internal stem changes (e.g., *wirf*-). Attributive adjective inflection is a completely regular – lexically unconditioned – affixation process that applies to any member of the category 'adjective' and consists of the base stem plus a set of portmanteau suffixes to encode gender, case, and number features (e.g., [[müde]+m] for the masculine dative singular form of the adjective *müde* 'tired'). From a morphological perspective, we may conceive of these affixes as exponents of inflectional rules that spell out the corresponding morphosyntactic feature set (Anderson, 1992; Aronoff, 1994). Following previous experimental research (Clahsen, Eisenbeiss, Hadler, & Sonnenstuhl, 2001; Opitz, Regel, Müller, & Friederici, 2013; Penke, Janssen, & Eisenbeiss, 2004), we assume that the recognition of these kinds of inflected adjective forms engages morphological computation processes – that is, stem+affix decomposition and the application of inflectional rules, after which the base stem becomes *directly* accessible. By contrast, after stem+affix decomposition of a finite verb form such as *wirft* ([[wirf]+t]), the base stem is only *indirectly* accessible, through a lexically conditioned alternative stem form (*wirf*-) with its morphosyntactic features. Given previous findings suggesting that grammatical computation is better maintained at old age than lexically mediated processes, we expect older speakers to efficiently access the morphosyntactic features encoded by affixed adjectives, while they may struggle to do so from marked verbal stems. Furthermore, previous work has found the processing of irregular forms at old age to be modulated by verbal memory skills (Clahsen & Reifegerste, 2017). If this finding has any general significance, we should find that older speakers' verbal-memory skills are correlated with their ability to extract morphosyntactic features from marked verbal stems.

Study 1: Adjective inflection in older Germans

While inflected adjective forms of German such as *müdes, müdem, müder, müden, müde* 'tired' share the same lemma, they also contain different affixes (*-s, -m, -r, -n, -e*) to encode grammatical case, number, and gender features. Furthermore, inflected adjectives are highly regular and transparent in German, producing concatenated forms that consist of an unaltered stem with or without a segmentable affix. Yet, in terms of their morphosyntactic feature content, word forms such as *müdes* or *müdem* are different from each other, and the question arises as to how these features are processed by the language user. In linguistic morphology, the lexeme's different inflected word forms are thought to comprise an inflectional paradigm, that is, a multi-dimensional matrix consisting of slots defined by morphosyntactic feature values. Paradigms provide productive systems for generating inflected word forms of any lexeme that belongs to a given syntactic category. The formation of paradigms is thought to be constrained by more general principles (Kiparsky, 1998; Wunderlich, 1996). In Wunderlich's account, for example, paradigm entries are required to be maximally informative and to avoid redundant feature specifications. Consequently, paradigm entries are underspecified in Wunderlich's account, with direct paradigm specifications for positive feature values only. For a binary morphosyntactic category such as Number, for example, plural forms receive a positive specification ([NUM: +PL]), whereas the corresponding singular forms do not require any extra specification for Number, but instead receive a negative feature value ([NUM: −PL]), simply by virtue of their paradigmatic opposition to a positively specified form. For the present study, we examined regular attributive adjective forms such as *müdes, müdem, müde* with the suffixes *-s, -m*, and *-e*. Table 1 illustrates their feature bundles according to Blevins' (1995) account. Here, following Bierwisch (1967), classification of the four cases involves the feature [±OBL], with [+OBL] for genitive and dative, and [−OBL] for nominative and accusative. As can be seen, *-m* is the most specified affix with two positive features, followed by *-s*, which again is more specified than the least specified affix *-e*; see also Wiese (1999) for a related account.

Table 1. Morphosyntactic feature specifications for *-e*, *-s*, and *-m*

-e	*-s*	*-m*
–	[−PL]	[−PL]
–	[−FEM]	[−FEM]
–	[−MASC]	–
[−OBL]	[−OBL]	[+OBL]
–	–	[+DAT]

This difference in specification dovetails with differences in frequency between the three forms, in that *-m* adjective forms have the lowest type and token frequencies in German corpora, followed by *-s* forms which are more frequent than *-m* forms, but less frequent than *-e* adjective forms; see Schriefers, Friederici, & Graetz (1992).

Attributive adjective inflection in younger adults has been examined in a number of experimental studies, most commonly with priming techniques (Bosch & Clahsen, 2016; Clahsen et al., 2001; Leminen & Clahsen, 2014; Schriefers et al., 1992), in addition to one sentence-matching (Penke et al., 2004) and one ERP violation study (Opitz et al., 2013). A common finding from the behavioral priming studies was a main effect of target type, with *-m* adjective forms being more difficult to prime than other target forms (Bosch & Clahsen, 2016; Clahsen et al., 2001; Schriefers et al., 1992). This contrast can be attributed either to the reduced frequency of *-m* adjective forms or to their morphosyntactic feature content, which is more specific than that of *-s* or *-e* target forms and hence likely to be more difficult to prime. In addition, some studies reported priming asymmetries, which are hard to explain in terms of frequency differences, but were instead attributed to the relative degree of feature specification for the prime and target forms (Bosch & Clahsen, 2016; Clahsen et al., 2001; Leminen & Clahsen, 2014). Specifically, cases in which the prime word contained all the morphosyntactic features of the target word (*müdes* → *müde*) led to smaller reductions of repetition priming (see Methods section for a more detailed explanation) than the reverse case in which the recognition of the target required the additional processing of morphosyntactic features not available from the prime (*müde* → *müdes*). This asymmetry in reduction of priming, which maps onto the feature specificity laid out in Table 1, led to the conclusion that younger German-speaking adults' speed of processing of regular inflected word forms is sensitive to the morphosyntactic feature content of these words. The aim of Study 1 was to determine whether this is also the case for older individuals.

Method

In order to assess the extent to which older speakers access morphosyntactic features contained in regular affixed adjectives, we conducted a cross-modal priming experiment. Following previous studies (Clahsen et al., 2001; Leminen & Clahsen, 2014; Bosch & Clahsen, 2016), we determined sensitivity to morphosyntactic features by calculating 'reductions of repetition priming' for the critical conditions compared to the repetition-priming condition (i.e., when the prime and the target are identical), for example, *müde* versus *müdem* as primes for the target *müdem*. Identical repetition should yield maximal priming as the prime activates the target word in its entirety, including all morphosyntactic information encoded in a given form. Other prime words may lead to reduced priming, depending on the properties of the target word that are and those that are not available from the prime word. In the prime-target pair *müde* → *müdes*, for example, the target contains unprimed morphosyntactic features (-PL, -FEM, -MASC) that are not encoded in the prime word, which should lead to reductions of repetition priming. In the reverse case, however, *müdes* → *müde*, the target does not contain any unprimed features, which should lead to no or smaller reductions of repetition priming. In this way, reductions of repetition priming provide a measure of how efficiently participants access the features contained in the prime.

Participants
We recruited 32 native speakers of German. See Table 2 for an overview of demographic participant information.

Table 2. Overview of biographical participant information

N	32		
Sex	23 female, 9 male		
Handedness	31 right-handed, 1 left-handed		
	mean	**SD**	**range**
Age	62.9	9.6	50–83
CERAD score (out of 100)	90.5	4.6	80–99
MMSE (out of 30)	29.2	0.9	27–30
Education (in years)	14.3	2.1	11–17
Goethe score (out of 30)	27.8	1.4	23–30

All participants completed the neuropsychological test battery of the 'Consortium to Establish a Registry for Alzheimer's Disease' (CERAD-Plus; www.memoryclinic.ch), comprising the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) and subtests assessing verbal fluency, picture naming, constructional praxis, and verbal memory. The CERAD composite score (Chandler et al., 2005) is the sum of a participant's scores for Verbal Fluency (Animal Naming; Isaacs & Kennie, 1973), the modified Boston Naming Test (Borod, Goodglass, & Kaplan, 1980), Constructional Praxis (Rosen, Mohs, & Davis, 1984) as well as Word List Learning, Recall, and Recognition Discriminability (Atkinson & Shiffrin, 1971), for a maximum score of 100. Five of these subtests (Verbal Fluency, Boston Naming Test, Word List Learning, Word List Recall, Word List Recognition) directly tap verbal-memory skills. Thus, the CERAD score may be viewed as a proxy of verbal memory, with people at the lower end of the continuum having relatively reduced verbal-memory skills. All participants scored above the threshold of 1.5 SDs below the population mean (corrected for sex, age, and education; Berres, Monsch, Bernasconi, Thalmann, & Stähelin, 2000) on each of the subtests, and no participant scored less than 27 points on the MMSE, suggesting that they were not affected by pathological memory decline. Furthermore, we assessed participants' general level of grammatical skill by administering the grammar subtest of the Goethe Institute Placement Test, a 30-item multiple-choice cloze test (www.goethe.de/cgi-bin/einstufungstest/einstufungstest.pl). The mean score our participants achieved puts them at the highest level of grammatical skill achievable in this test.

Materials

Participants saw 72 monomorphemic adjectives in three morphological variants: *-e* (e.g., *blaue*), *-s* (*blaues*), and *-m* (*blauem*), 'blue'. All forms were presented as primes and targets distributed over different lists using a Latin-Square design; see Table 3 for an overview of the conditions.

Table 3. Prime-target pairs for Study 1

Prime affix	Target affix		
	-e	*-s*	*-m*
-e	*blaue → blaue*	*blaue → blaues*	*blaue → blauem*
-s	*blaues → blaue*	*blaues → blaues*	*blaues → blauem*
-m	*blauem → blaue*	*blauem → blaues*	*blauem → blauem*

Adjective forms ending in *-e* are significantly more frequent (*M* = 33.31 per million) in the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995) than forms ending in *-s* (*M* = 5.82), which are in turn more frequent than forms ending in *-m* (*M* = 2.86). The items used in the experiment stem from a wide range of lemma frequencies (10–929 per million), with a mean of 169 occurrences per million (*SD* = 214.46). See Appendix A in Bosch and Clahsen (2016) for detailed frequency counts. The items did not differ in semantic relatedness between conditions as they were all inflected forms of the same base form (*blau* in the example in Table 3). The 72 experimental items were mixed with 36 additional adjective pairs as well as with 72 verb pairs, for a total of 180 word-word pairs. These were mixed with 180 word-nonword pairs, resulting in a total of 360 item pairs. The 180 word-nonword pairs consisted of 72 pairs with verb forms as primes and targets and 108 adjectival ones. Nonwords were created by exchanging at least two letters of an existing verb's or adjective's stem, leaving the onset and the coda intact. Note that form overlap (as measured by spatial coding; Davis, 2000) between word-nonword pairs (*M* = 0.63, *SD* = 0.15) was slightly lower than that between word-word pairs (*M* = 0.86, *SD* = 0.15, across items in Study 1 and 2).

Procedure

The procedures were adopted from previous cross-modal priming experiments with younger adults (Clahsen et al., 2001; Bosch & Clahsen, 2016). The items were presented on a laptop with a 17-inch screen using DMDX (Forster & Forster, 2003). Each trial started with a fixation point (800 ms), followed by a beep (200 ms), and the auditory prime. At the offset of the prime, a visual target word appeared and remained on the screen for 500 ms for a lexical (word/non-word) decision. Note that the 200 ms target-presentation time used with younger adults was increased to 500 ms in the current study to do justice to the general slowing of reading speed in older individuals, for instance due to age-related non-pathological loss in visual acuity (Cheong, Legge, Lawrence, Cheung, & Ruff, 2008; Curcio, Owsley, & Jackson, 2000; Spear, 1993). After the target word disappeared, participants had another 2000 ms to make their lexical decision before the beginning of the next trial. Reaction time (RT) measurement started with the onset of the target word on the screen. Participants were tested individually in a quiet room and were instructed to perform a lexical decision on presented targets by using a game pad with two highlighted buttons for 'YES' and 'NO' responses, with the dominant hand controlling the 'YES' button. The experimental session was preceded by a practice phase including 20 trial items with 10 word and 10 non-word targets. Before the experiment, participants filled out a short biographical questionnaire. After the experiment, the CERAD and the Goethe test were administered.

Data analysis and model selection

For all RT analyses, we excluded incorrect responses from further analysis as well as response times below or above 2 SDs on a per-participant-per-condition basis, leading to the exclusion of 2.15% of data points. We fit linear mixed-effects regression models using the languageR package (Baayen, 2013) and the lme4 package (Bates, Maechler, Bolker, & Walker, 2014) to analyze the RT data. By employing backwards elimination, the model that best accounts for the log-transformed RTs was identified. Fixed factors of interest were PRIME AFFIX (*-e*/*-s*/*-m*), TARGET AFFIX (*-e*/*-s*/*-m*), and CERAD SCORE (continuous, centered), as well as their interaction. PRIME FORM FREQUENCY (continuous, centered) and TARGET FORM FREQUENCY (continuous, centered) were added as log-transformed covariates to control for the contribution of form-frequency differences between the different conditions. FORM OVERLAP, as measured using spatial coding (Davis, 2000) was added to control for differences in the amount of form overlap between different conditions. TRIAL NUMBER (the position of the item in the experimental list; continuous, centered) was added as a predictor to remove residual auto-correlation and to control for trial-level task effects (Baayen & Milin, 2010). Random factors were Participants and Items. Following Barr, Levy, Scheepers, and Tily (2013), we started with a maximal random-effects structure and simplified the model in cases of convergence failure. This led to the inclusion of PRIME AFFIX and TARGET AFFIX as by-participant random intercepts. Following common practice, we used *t*-values (and *z*-values for categorical data) to assess 'significance', with the threshold for significance set at 1.96.

Results

Accuracy rates in the lexical-decision task for target word forms were close to ceiling for our participants in all conditions (98.7%). Accuracy was not affected by PRIME AFFIX, TARGET AFFIX, or CERAD SCORE (all $p > .1$).

Table 4 shows the RT data broken down by condition.

Table 4. Mean RTs (in ms) and standard deviations (in parentheses) in Study 1

Prime affix	Target affix			
	-e	*-s*	*-m*	**Across targets**
-e	658 (189)	717 (215)	733 (221)	703 (211)
-s	694 (226)	640 (169)	770 (227)	702 (216)
-m	716 (224)	703 (191)	700 (196)	707 (204)
Across primes	690 (215)	687 (195)	735 (217)	

As two of the three fixed factors of interest contain three levels, model comparisons were employed using the anova() function to assess the significance of effects of the fixed factors as main effects as well as their interaction. To assess the significance of main effects, we compared a model containing a given main effect to a model without this factor. The significance of interactions was assessed by comparing a model containing the interaction in question either (in the case of a higher-level interaction) to a model containing only the relevant lower-level interactions or (in the case of a two-way interaction) to a model containing only the relevant main effects.

We found a main effect of TARGET AFFIX ($\chi^2(7) = 38.764$, $p < .001$), indicating differences in the speed with which participants responded to the different types of targets across prime types. This contrast is due to significantly longer RTs for *-m* targets than for *-e* or *-s* targets (*-m* vs. *-e*: $\beta = -0.0541$, $SE = 0.0146$, $t = -3.72$; *-m* vs. *-s*: $\beta = 0.0313$, $SE = 0.0142$, $t = 2.21$); there was no difference between *-e* and *-s* targets ($\beta = 0.0214$, $SE = 0.0285$, $t = 0.75$). There was no main effect of PRIME AFFIX ($\chi^2(7) = 3.0326$, *ns*), indicating that across target types, none of the different prime affixes led to shorter RTs than the other two. Further, we found a marginally significant main effect of CERAD SCORE ($\chi^2(1) = 3.2923$, $p = .070$), with higher scores leading to shorter RTs.

We also found a two-way interaction between PRIME AFFIX and TARGET AFFIX ($\chi^2(4) = 61.3830$, $p < .001$), while the other two-way interactions were not significant (PRIME AFFIX x CERAD SCORE: $\chi^2(2) = 2.2423$, *ns;* TARGET AFFIX x CERAD SCORE: $\chi^2(2) = 2.4976$, *ns*). Lastly, there was no three-way interaction between PRIME AFFIX, TARGET AFFIX, and CERAD SCORE ($\chi^2(4) = 5.3946$, *ns*).

In sum, the model that provides the best fit of the data contains the interaction of PRIME AFFIX and TARGET AFFIX and a main effect of CERAD SCORE (plus the covarying factors PRIME FORM FREQUENCY, TARGET FORM FREQUENCY, FORM OVERLAP, and TRIAL NUMBER). In order to understand the nature of the interaction, the two factors PRIME AFFIX and TARGET AFFIX were successively releveled to compare the RTs in the different priming conditions to one another. Table 5 presents an overview of the magnitudes of reductions of priming for all prime-target pairs relative to the respective repetition-priming condition; that is, the difference between a given morphological-priming condition (e.g., *-s* forms priming *-e* forms) and the relevant identity-priming condition (e.g., *-e* forms priming *-e* forms).

Table 5. Magnitudes of reductions of repetition priming (in ms and as Cohen's d)

Prime affix	**Target affix**		
	-e	***-s***	***-m***
-e	–	77 ms (d = .40)	33 ms (d = .16)
-s	36 ms (d = .17)	–	70 ms (d = .33)
-m	58 ms (d = .28)	63 ms (d = .35)	–

In each of the three target-affix conditions, identity priming led to significantly shorter RTs than any of the other two prime affixes. That is, *-e* → *-e* led to significantly shorter RTs than *-s* → *-e* ($\beta = 0.0487$, $SE = 0.0197$, $t = 2.47$) and to significantly shorter RTs than *-m* → *-e* ($\beta = 0.0641$, $SE = 0.0247$, $t = 2.60$), *-s* → *-s* led to significantly shorter RTs than *-e* → *-s* ($\beta = 0.1033$, $SE = 0.0221$, $t = 4.67$) and to significantly shorter RTs than *-m* → *-s* ($\beta = 0.0947$, $SE = 0.0195$, $t = 4.85$), and *-m* → *-m* led to significantly shorter RTs than *-e* → *-m* ($\beta = 0.0651$, $SE = 0.0265$, $t = 2.45$) and to significantly shorter RTs than *-s* → *-m* ($\beta = 0.0898$, $SE = 0.0199$, $t = 4.51$). In other words, all of the magnitudes of reductions of repetition priming displayed in Table 5 are significant, relative to the identity condition.

Another finding is an interesting asymmetry for one of the three prime-target combinations. Specifically, the difference between *-s* → *-e* and identity priming was significantly smaller than the difference between *-e* → *-s* and identity priming (36 ms vs. 77 ms, $t = 2.16$). This was not the case for the other prime-target combinations, for which the two respective directions led to reductions of priming of similar size, *-m* → *-e* vs. *-e* → *-m*: ($\beta = 0.0063$, $SE = 0.0336$, $t = 0.19$) and *-m* → *-s* vs. *-s* → *-m*: ($\beta = 0.0019$, $SE = 0.0263$, $t = 0.35$).

In addition to the effects of different affixes as primes and targets, we found a main effect of TARGET FORM FREQUENCY (β = −0.0154, *SE* = 0.0068, *t* = −2.26), but no effect of PRIME FORM FREQUENCY (β = −0.0023, *SE* = 0.0069, *t* = −0.33) and no interaction between PRIME FORM FREQUENCY and TARGET FORM FREQUENCY (β = −0.0039, *SE* = 0.0030, *t* = −1.30). There was also no effect of FORM OVERLAP on RTs (β = −0.3371, *SE* = 0.3817, *t* = −0.88).

Additional analyses
A reviewer pointed out that in some of the morphological test conditions (viz., *-s* → *-e* and *-m* → *-e*), a given target form, for example *müd*e, is fully contained in the prime that preceded it (e.g., *müdes, müdem)* and that this kind of 'nestedness' may lead to greater facilitation than for conditions in which the target was not fully contained in the prime. To address this concern, we recoded TARGET AFFIX as TARGET TYPE with the levels 'nested' (*-e* targets) versus 'non-nested' (*-m* and *-s* targets) and PRIME AFFIX as PRIME TYPE with the levels 'identity' versus 'morphologically related'. We then conducted a linear mixed-effects regression on the data using the same covariates as laid out in the original analysis. We found a main effect of PRIME TYPE (*t* = 2.30), with faster RTs for the identity condition across target types, a main effect of CERAD SCORE (*t* = −2.13) due to faster RTs for participants with higher memory scores, and a main effect of TARGET FORM FREQUENCY (*t* = −3.49) reflecting faster RTs for more frequent target forms. There were no other main effects or interactions. Importantly, we did not find an interaction between PRIME TYPE and TARGET TYPE (*t* = 0.13), suggesting that the overlap that is present in pairs such as *blaues*→*blaue* and *blauem*→*blaue* did not lead to greater facilitation than pairs without such an overlap. In other words, the priming patterns we found in the original analyses cannot be attributed to differences in 'nestedness' for the different prime-target pairs.

Discussion

Study 1 asked whether older individuals in their sixties and beyond extract morphosyntactic features from regularly inflected word forms during on-line language comprehension. Given the results presented above, the answer to this question is a clear 'yes'. We found (i) a significant repetition-priming effect for all target types, (ii) a target-form effect, with *-m* forms eliciting longer RTs than *-e* or *-s* forms, and (iii) an asymmetry for a particular prime-target combination (viz., *-s* → *-e* vs. *-e* → *-s*). Taken together, these results indicate that our participants' speed of lexical access is sensitive to the feature content of primes and targets.

Consider first the repetition-priming effects. Immediate repetition priming during word recognition is a common finding from many word-recognition studies, mostly with younger adults (Forster & Davis, 1984). The facilitative effect can be conceived of as a consequence of residual activation of the prime word that is still available when – immediately after the prime – the same item is presented as a target for lexical decision or naming. A review of priming studies by Fleischman (2007) found priming to be intact in healthy older speakers. The repetition-priming effect we obtained in Study 1 is consistent with this finding.

Our second finding is that the type of target affix affected participants' responses, with *-m* forms yielding significantly longer RTs than other adjective forms, while there were no such differences between *-e* and or *-s* forms. Note that the frequency distribution of these forms in German usage provides only a partial account for this finding. That *-m* forms produced longer RTs could be due to their relatively low frequency compared to other adjectival affixes. However, if frequency was the crucial predictor, we should also have found shorter RTs for *-e* than for *-s* forms, as the former are twice as frequent in German usage as the latter (Schriefers et al., 1992). This was not the case, however, indicating that frequency differences have limited explanatory value in the current case.

As an alternative, consider the morphosyntactic feature content of the different target affixes. According to the feature matrix in Table 1 (which contains the feature specifications for the three affixes tested), what is common to *-e* and *-s* is that they contain only negative feature values, whereas *-m* has two features with positive values ([+OBL] and [+DAT]). Recall that positive feature values are supposed to add new information, whereas the corresponding negative (= unmarked) feature values are automatically assigned. From this perspective, the pattern of target RTs we obtained – that is, longer RTs for *-m* forms without any difference between *-e* and *-s* forms – can be interpreted as a 'specificity effect': *-m* (but not *-e* or *-s*) forms contain positively specified features, which are not available from any other adjective form and are therefore harder to prime than *-e* or *-s* forms.

Finally, our results revealed an interesting priming asymmetry for *-s* versus *-e* forms: *-s* forms primed *-e* target forms significantly better than *-e* forms primed *-s* target forms. Hence, for the same word pairs (e.g., for *blaues* vs. *blaue*), the direction of priming yielded a contrast in word recognition. For the other two prime-target pairings we tested (*-s* vs. *-m* and *-m* vs. *-e*), there were no reliable asymmetries. We suggest that these patterns can be explained in terms of the stimuli's morphosyntactic features. Consider first, however, other factors to account for the observed priming patterns. As regards *form frequency*, recall that the best-fit model to explain our data included both PRIME FORM FREQUENCY and TARGET FORM FREQUENCY to control statistically for the influence of frequency differences. Nevertheless, even when co-varying out frequency, we found the aforementioned priming asymmetry (as indicated by an interaction between PRIME AFFIX and TARGET AFFIX), confirming that frequency differences cannot explain the priming patterns we obtained.

Secondly, different degrees of *formal (orthographic/phonological) overlap* between prime-target conditions may also account for priming effects. To take a relevant case, Basnight-Brown, Chen, Hua, Kostić, and Feldman (2007) found greater facilitation for so-called nested targets (e.g., *guided-guide* and *drawn-draw*) compared to non-nested targets (e.g., *run-ran*). This contrast also applies to our prime-target conditions in which some targets are nested and others are not (e.g., *blaues* → *blaue* vs. *blaues* → *blauem*). Note, however, that the same contrast in terms of 'nestedness' was present in pairs such as *blauem* → *blaue* vs. *blaue* → *blauem*, and that these pairs did not yield any kind of priming asymmetry. We also performed additional analyses to directly test for the role of 'nestedness'; these analyses did not yield any main effects of or interactions with the factor 'nestedness', indicating that the priming patterns we obtained cannot be explained in these terms.

Consider the priming asymmetries in terms of the morphosyntactic features involved. When an *-e* form is the prime and a form with *-s* the target, the target contains features (for gender and number) that are not already available from the prime, whereas in the reverse case, *-s* → *-e*, the target form does not have any unprimed features. Unprimed features may be assumed to reduce repetition priming, hence the significant asymmetry in priming for these conditions. For the other two prime-target pairings, *-s*/*-m* and *-e*/*-m*, the target forms always contain unprimed features or even feature mismatches, which impede repetition priming irrespective of the priming direction. In the case of *-s* → *-m*, the case features of *-m* ([+DAT], [+OBL]) are unavailable from the prime, and in the reverse case, *-m* → *-s*, the [+OBL] feature of *-m* clashes with the [−OBL] feature of *-s*. Likewise, for *-e* → *-m*, the target form contains unprimed (case) features, and for *-m* → *-e*, the [+OBL] feature of *-m* again clashes with the [−OBL] feature of *-e*. In this way, a feature-based approach can account for the specific pattern of priming asymmetries we obtained, which in turn indicates that our older participants were able to access and process the morphosyntactic information encoded in regular inflected adjectives.

Finally, we note that the asymmetric pattern did not seem to be modulated by participants' verbal memory. A marginal main effect of CERAD SCORE indicated that people with better verbal-memory skills showed a trend of faster performance. Recall that this composite score consists of several subtests, most of which tap lexical access, such as verbal fluency and picture naming. It is thus not surprising that participants who achieve a high score in this test also tend to show faster RTs in a lexical-decision task. It is, however, also noteworthy that the aforementioned interaction between PRIME AFFIX and TARGET AFFIX – which serves as the diagnostic of morphosyntactic feature access – is not modulated by CERAD SCORE, indicating that across the entire verbal-memory range tested, participants accessed the features contained in inflected adjectives.

Study 2: Inflected verbs with marked stems in older Germans

In this section, we investigate a different case, namely whether older native speakers' access of morphosyntactic features from lexically conditioned (irregular) forms is also unaffected. We specifically examine irregular marked verbal stems of German, which are common for inflected verb forms of a limited number of so-called strong and mixed verbs. Marked stems are phonologically and orthographically different from the unmarked stems of the infinitive forms of these verbs. There are about 200 base verbs with marked stems, which are selected for various inflected verb forms encoding a range of morphosyntactic features, for example, past tense, past participle, and subjunctive (*werf-* 'throw-', [+Past]: *warf-*, [+Part.]: *worf-*, [+Subj.]: *würf-*). In addition, a subset of strong verbs has marked stems for certain present-tense forms. These so-called secondary present-tense stems (Wiese, 2008) have two variants, one with a fronted stem vowel and the other with a raised stem vowel (e.g., *wasch-* 'wash' → *wäsch-* 'wash', *werf-* → *wirf-*). Amongst present-tense forms, these marked stems are required for 2nd and 3rd person singular indicative forms paired with the corresponding regular suffixes *-st* and *-t*, for example, *wäsch-st* '(you) wash' or *wirf-t* '(s/he) throws'.

From a linguistic perspective, these kinds of marked stems represent a case of 'lexically conditioned suppletive allomorphy' (Paster, 2016: 181); that is, they are not determined by regular phonological rules (hence 'suppletive') and are idiosyncratic to particular lexical items (hence 'lexically conditioned'). Historically, these marked stems derived from phonological ('ablaut') rules. For modern German, sets of alternation rules have been proposed to capture the vowel changes from unmarked to marked stems, for example, /i/ → [ɔ] if followed by a voiceless continuant as in *schieß-* → *schoss-* 'shoot → shot [+Past]' (e.g., Barbour, 1982; Beedham, 1994). Note, however, that these rules are unproductive in modern German with many exceptions (Durrell, 1980, 2001; Wiese, 1996).

From a psycholinguistic perspective, the processing of marked stems requires accessing lexical exceptions. One suggestion is that marked stems form associative clusters held together by semantic and/or phonological similarity. Smolka, Zwitserlood, and Rösler (2007) suggested, for example, that the various stem forms of strong verbs in German (e.g., *werf-*, *wirf-*, *warf-*, *worf-*, *würf-*, *wurf*) form a semantic cluster as they activate a shared concept (e.g., 'throw'). Günther (1988) proposed an account of German verb stems using Lukatela, Carello, and Turvey's (1987) satellite model. Bittner (1996) and Köpcke (1998) noted that the stem-alternation patterns of the strong and mixed verbs of German form phonological similarity clusters, parallel to the similarity clusters amongst the irregular verbs in English (Prasada & Pinker, 1993). For instance, unmarked stems with a medial high front vowel /ɪ/ and a velar nasal /ŋ/ (e.g., *singen*, *sinken*, *ringen*, *wringen*, etc.) have marked stems with the same vowel changes.

An alternative proposal to these associative models of stem representation holds that marked stems constitute subnodes of hierarchically structured lexical entries and lexical templates. Wunderlich (1996) developed such an account for the verbal stems of German, specifically using default inheritance networks (Hippisley, 2016). Consider Figure 1 as an example of the stem allomorphs of the German verb *werfen* 'to throw'. The base stem (*werf-*) at the top is the most impoverished stem form, while the subnodes are specified for phonological changes and/or morphosyntactic feature values. The subnodes inherit all information from their respective mother node except for the features they add or replace, with the subnodes themselves being minimally specified to avoid redundancy. The leftmost subnode is specified for the vowel change (e.g., *werf-* → *wirf-*) plus the feature [−1] for 2nd and 3rd person; the imperative form (+IMP) is inherited from this subnode capturing the fact that strong verbs that have marked stems in the imperative also have marked 2nd and 3rd person forms, but not vice versa; compare, for example, *geben – gib! – gibst* 'to give – give! – give-2nd-sg.', but *werden – werde! – wirst* 'to become – become! – become-2nd sg.'. The subnode […a…]$_{+PRET}$ is for preterit stems (e.g., *warf-*) from which subjunctives (e.g., *würf-*) are inherited, and finally the stem [..o..n]$_{+PART}$ for (irregular) participle forms (e.g., *(ge)worfen*).

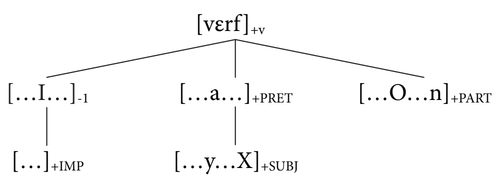

Figure 1. The stem *werf-* and its subentries in a default inheritance network

This kind of lexically-conditioned stem allomorphy has been examined in a number of experimental studies with younger adults, mostly using priming techniques (e.g., Clahsen et al., 2001; Krause, Bosch & Clahsen, 2015; Smolka et al., 2007), as well as elicited production tasks (e.g., Clahsen, Prüfert, Eisenbeiss, & Cholin, 2002). The native-speaker participants in these studies were all university students in their twenties. A common finding from these priming studies was an asymmetry between marked and unmarked stem forms. Whilst marked stems were found to efficiently prime unmarked ones, the reverse case – unmarked stems as primes – yielded reduced facilitation on the recognition of marked ones. For example, *warf-* → *werf-* produced smaller reductions of priming (relative to the identity condition *werf-* → *werf-*) than the case of *werf-* → *warf-* (relative to *warf-* → *warf-*;

Clahsen et al., 2001). This priming pattern has been taken to indicate that younger German-speaking adults' speed of processing of irregular word forms is sensitive to the morphosyntactic feature content of these words. In the following, we report whether this is also the case for older individuals.

Method

As in Study 1, Study 2 used reductions of repetition priming to assess the extent to which older speakers access the morphosyntactic features encoded in inflected forms. We compared the critical conditions to corresponding identity conditions, for example, *werfen* versus *wirft* as primes for the target *wirft* and examined whether prime-target pairs in which the prime contained all the features necessary to process the target (more specific prime → less specific target) led to smaller reductions of repetition priming than the reverse case, in which the recognition of the target word requires the processing of additional features (less specific prime → more specific target). In this way, we determined how older speakers' speed of processing is affected by the morphosyntactic feature content encoded by marked stems.

Participants

The participants of Study 2 were the same 32 native speakers of German that were tested for Study 1; see Table 2 for an overview of their biographical and demographic details.

Materials

The critical items consisted of inflected forms of 32 German strong verbs that have secondary present-tense stems, 18 verbs with an *-e-* stem in the infinitive and an *-i-* stem in the 2nd and 3rd singular present tense (e.g., *werfen* – *wirft*, 'to throw' – 'throw-3RD.SG') and 14 verbs with an *-a-* stem in the infinitive and an umlauted stem in 2nd and 3rd singular present tense (e.g., *waschen* – *wäscht*, 'to wash' – 'wash-3RD.SG'). Participants were presented with infinitive forms and 3rd person singular present-tense forms of these verbs as primes and targets, which were distributed over four lists using a Latin Square design; see Table 6 for an overview of the conditions. These stimuli were taken from Krause et al. (2015). Primes and targets were matched group-wise for word-form frequency (infinitives: $M = 59.6$, 3rd singular present-tense forms: $M = 57.6$). The items had a wide range of base-stem frequencies (2–3436 occurrences per million), with a mean of 603 per million ($SD = 884.41$). See Krause et al. (2015) for additional details. The 32 critical prime-target pairs were mixed with 148 word-word filler pairs and 180 word-nonword pairs, for a total of 360 items; the 180 word-nonword pairs were the same as in Study 1. Note that the *-en* affix as for example in *werf-en* is ambiguous in that it may encode 3rd/1st pl. or infinitives. However, if presented in isolation, it is most likely to be identified as an infinitival form. We further assume that because the infinitival form is not specified for any of the person/number features that finite forms such as *wirft* are specified for, feature conflicts between these forms and infinitives do not arise.

Table 6. Prime-target pairs for Study 2

Prime type	Target form	
	Marked stems	**Unmarked stems**
Test	*werfen* → *wirft*	*wirft* → *werfen*
Identity	*wirft* → *wirft*	*werfen* → *werfen*

Procedure and data analysis

The experimental procedure and data-analysis techniques were the same as for Study 1. Due to an unusually low mean accuracy score, the item *quellen* 'to ooze' was removed from all analyses. For the analysis of the RT data, we also excluded incorrect responses and outliers (RTs below or above 2 SDs of the mean by participant and by condition), which – taken together – resulted in the exclusion of 5.2% of the entire data set for Study 2. Fixed factors in the linear mixed-effects model were PRIME TYPE (identity/test), TARGET FORM (marked stem/unmarked stem), CERAD SCORE, and their interactions, as well as TRIAL NUMBER (continuous), PRIME FORM FREQUENCY (continuous), TARGET FORM FREQUENCY (continuous), and FORM OVERLAP (continuous), all of which were centered. Random factors were Participants and Items. The interaction of PRIME TYPE and TARGET FORM was included as a by-participant random intercept (Barr et al., 2013). Otherwise, the statistical analysis was parallel to Study 1.

Results

Accuracy rates in the lexical-decision task for target word forms were close to ceiling for our participants in all conditions (99.3%). Accuracy was not affected by PRIME TYPE or TARGET FORM (all $p > .1$). No further analyses were performed on the accuracy data.

Table 7 shows the RT data broken down by condition, and Table 8 presents the model that provided the best fit to these data.

We found a marginally significant main effect of PRIME TYPE, due to shorter RTs in the identity than the test conditions. Further, we found a significant main

Table 7. Mean RTs (in ms) and standard deviations (in parentheses) in Study 2. The bottom row shows differences between prime types (in ms and as Cohen's d)

Prime type	Target form		
	Marked stems	Unmarked stems	Across targets
Test	684 (145)	648 (149)	666 (148)
Identity	620 (172)	589 (141)	604 (158)
Across primes	652 (162)	618 (148)	635 (156)
Differences	64, $d = 0.40$	59, $d = 0.41$	

Table 8. The best-fit linear mixed-effects model for the RT data of Study 2

Random effects:	Name	Variance	SD	Correlations		
Participant	Intercept	0.0149	0.1222			
Item	Intercept	0.0016	0.0406			
	Target Type	0.0042	0.0645	−0.49		
	Prime Type	0.0007	0.0260	−0.53	−0.47	
	Target Form: Prime Type	0.0088	0.0936	0.84	−0.89	0.01
Residual		0.0294	0.1715			
Fixed effects:		**β**	**Standard error**		**t value**	
Intercept		6.4280	0.0247		260.54	
Prime Type		0.1193	0.0675		1.77	
Target Form		−0.0416	0.0179		−2.33	
CERAD Score		−0.0155	0.0049		−3.17	
Trial Number		−0.0003	0.0001		−4.05	
Form Overlap		0.0434	0.1428		0.30	
Prime Form Frequency		−0.0037	0.0132		−0.28	
Target Form Frequency		−0.0114	0.0132		−0.87	
Prime Type: Target Form		−0.0228	0.0324		−0.70	
Prime Type: CERAD Score		−0.0045	0.0025		−1.78	
Target Form: CERAD Score		−0.0015	0.0025		−0.59	
Prime Form Frequency: Target Form Frequency		0.0016	0.0025		0.64	
Prime Type: Target Form: CERAD Score		−0.0115	0.0050		−2.29	

*Formula in R: DV ~ 1 + Prime Type * Target Form ** CERAD Score + *Prime Form Frequency * Target Form Frequency + Trial Number + Form Overlap + (1 + Prime Type * Target Form | participant) + (1 | item)*

effect of TARGET FORM, due to shorter RTs for target forms with unmarked than for those with marked stems. CERAD SCORE also significantly affected target RTs, with faster RTs for speakers with higher scores. Crucially, we also found a significant interaction between PRIME TYPE, TARGET FORM, and CERAD SCORE. For the condition 'more specific prime → less specific target', that is, prime words with marked stems and target words with unmarked stems (e.g., *wirf-* → *werf-*), CERAD Score modulated the magnitude of reduction of repetition priming; the greater a person's CERAD Score, the smaller the reduction of priming ($\beta = -0.0100$, $SE = 0.0035$, $t = 2.85$). For the reverse case, on the other hand, that is, the condition 'less specific prime → more specific target' (e.g., *werf-* → *wirf-*), a person's CERAD Score did not affect reduction of repetition priming ($\beta = 0.0022$, $SE = 0.0037$, $t = 0.60$). Figure 2 illustrates this interaction. RTs were not significantly affected by PRIME FORM FREQUENCY, TARGET FORM FREQUENCY, the interaction of these two factors, or FORM OVERLAP.

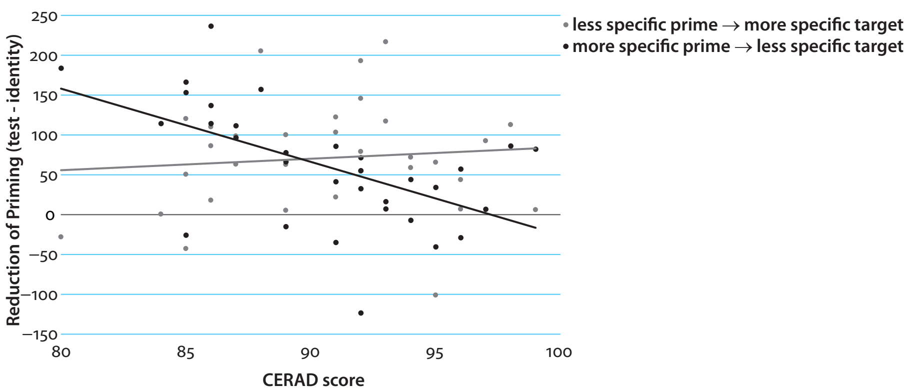

Figure 2. Reductions of priming by CERAD scores. Each dot represents one participant's reduction of repetition-priming for the two conditions 'more specific prime → less specific target' (black dots and black regression line) and 'less specific prime → more specific target' (grey dots and grey regression line)

Additional analyses

A further analysis was motivated by the fact that in Study 1, the priming patterns obtained were not affected by participants' memory skills as measured by their CERAD scores, whereas in Study 2 they were. Recall that Study 1 produced a PRIME AFFIX by TARGET AFFIX interaction which was due to an asymmetric priming pattern, such that primes which encode all the morphosyntactic features of the target (*-s* forms priming *-e* forms) led to greater facilitation (as evidenced by smaller reduction in repetition priming) than the reverse case (*-e* forms priming *-s* forms). The picture for Study 2 was more complex, in that the two-way interaction between PRIME TYPE and TARGET FORM was modulated by participants' CERAD SCORES. As the participants in the two experiments were the same, we performed an additional coordinated analysis to directly assess the role of the CERAD scores in the two experiments. Consider first Table 9 which displays the differences in reductions in repetition priming for the two experiments in the relevant prime-target conditions. Here 'more specific → less specific' refers to *-s* → *-e* in Study 1 and to marked stem → unmarked stem (e.g., *wirft* → *werfen*) in Study 2; 'less specific → more specific' refers to the reverse cases.

Table 9. Overview of the reductions of repetition priming (morphological condition – identity condition) in the two experiments (cf. Tables 5 and 7)

Study	**Direction of priming**	
	more specific → less specific	**less specific → more specific**
Study 1: Adjectives	36 ms, *d* = .17	77 ms, *d* = .40
Study 2: Verbs	59 ms, *d* = .41	64 ms, *d* = .40

The mean magnitudes in Table 9 were calculated by subtracting from the target RT of the test condition the RT of the respective identity condition. We then fit mixed-effects models to these reductions of repetition priming with ITEM TYPE (2 levels: Adjectives/Verbs), PRIMING DIRECTION (2 levels: more specific → less specific / less specific → more specific), and CERAD SCORE (continuous) as fixed factors. As the reductions of priming were calculated across items on a per-participant basis, only Participants was used as a Random Factor, with ITEM TYPE and PRIMING DIRECTION as by-participant random intercepts. See Table 10 for the best-fit model.

Table 10. The best-fit linear mixed-effects model for the reductions of repetition priming from Study 1 and Study 2

Random effects:	**Name**	**Variance**	**SD**	**Correlations**	
Participant	Intercept	0.2113	0.4596		
	Item Type	1.2267	1.1076	−0.67	
	Priming Direction	0.7315	0.8553	−0.31	0.91
Residual		0.6731	0.8204		
Fixed effects:		**β**	**Standard error**		**t value**
Intercept		4.0374	0.1164		34.69
Item Type		0.0283	0.2165		0.13
Priming Direction		0.1833	0.2492		0.74
CERAD Score		−0.0264	0.0263		−1.00
Item Type: Priming Direction		−0.3652	0.3477		−1.05
Item Type: CERAD Score		0.0177	0.0439		0.40
Priming Direction: CERAD Score		−0.0358	0.0527		−0.68
Item Type: Priming Direction: CERAD Score		0.2180	0.0885		2.46

*Formula in R: DV ~ 1 + Item Type * Priming Direction ** CERAD Score + *(1 | participant)*

The model revealed a three-way interaction between ITEM TYPE, PRIMING DIRECTION, and CERAD SCORE, which was due to an interaction of PRIMING DIRECTION and CERAD SCORE in Study 2 ($t = 3.26$), but not in Study 1 ($t = 0.35$). Hence, this coordinated analysis confirms that greater CERAD Scores lead to smaller reductions in repetition priming for verb primes with marked stems and targets with unmarked stems, but not for the reverse priming direction. For the regularly inflected adjectives tested in Study 1, however, the effect of PRIMING DIRECTION on reductions of priming was not modulated by CERAD SCORE.

Discussion

Study 2 investigated morphosyntactic feature access during on-line language comprehension from verb forms with irregular marked stems in older individuals. Using cross-modal priming of forms containing marked and unmarked stems, we found (i) a repetition-priming effect for both marked and unmarked target forms, (ii) a target-form effect with longer RTs for forms with marked stems, and (iii) an interaction between PRIME TYPE, TARGET FORM, and CERAD SCORE, such that CERAD Score (which is taken as a proxy for verbal memory) modulated the reductions of priming from marked primes, but not from unmarked primes.

The repetition-priming effect was due to the fact that participants were faster to respond to items after being primed with the same item compared to a morphologically related form. This effect indicates that participants were able to process the auditory prime and replicates the analogous finding from Study 1.

The second finding, target forms with marked stems (e.g., *wirft*) yielding significantly longer RTs than those with unmarked stems (e.g., *werfen*), may be due to a number of differences between these forms. One reason could be that marked stems are richer in terms of their morphosyntactic feature content than unmarked base stems, with the marked ones we tested being specified for present tense and for 2nd and 3rd singular (which in Wunderlich's (1996) account has the additional feature [−1], see Figure 1). A second related factor contributing to longer RTs for marked stems is that they are less common than unmarked ones, both within the verbal paradigm and in German usage.[1] Thirdly, and perhaps most importantly, the word form that contained the unmarked stem was the infinitive, that is, the citation form of verbs in German (e.g., *werfen* 'to throw'), which as such is likely to promote faster lexical-decision times than a corresponding finite 3rd singular form (e.g., *wirft*); see, for example, Lukatela et al. (1987) and related work within the so-called 'satellite' model.

1. Note, however, that the specific items used in this study were matched for form frequency and that we did not find any significant effects of form frequency.

Finally, we observed that participants' CERAD Scores affected the efficiency of priming for marked primes on unmarked targets, but not in the reverse case. How might this interaction come about? Consider the processes necessary to recognize the two types of target form. When a participant hears a form with a marked stem (e.g., *wirft*) and is then asked to perform a lexical decision on a target form of the same word with an unmarked stem (e.g., *werfen*), all the morphosyntactic features encoded by the target are already contained in the prime. If a participant is able to access the morphosyntactic features contained in this more specific prime, this should lead to more efficient priming (as evidenced by smaller reductions of repetition priming) compared to a case in which these features are not available from the prime. Our data indicate that the amount of facilitation from a more specific prime is modulated by a participant's CERAD Score (which is taken as a proxy for verbal memory), with people with higher scores showing greater facilitation (as evidenced by smaller reductions of repetition priming). We suggest that this modulation is due to the fact that accessing a marked stem and its features challenges verbal memory, and therefore works more efficiently for individuals with high than for those with low CERAD scores.

In the reverse case, however, in which a participant recognizes a form with a marked stem after being primed with an unmarked stem, the target form contains an unprimed morphosyntactic feature (viz., [−1]), which requires additional processing before a lexical decision can be made. The prime, however, is a fully regular form (e.g., *werfen*) that does not require any form-specific lexical access beyond the retrieval of the base stem. Reductions of repetition priming in this condition are therefore not modulated by the participants' verbal-memory skills.

General discussion

The main findings from the current paper are twofold: First, our results indicate that older native speakers' speed of processing of regular inflected word forms is sensitive to the morphosyntactic feature content of these words. Second, the efficiency with which these speakers deploy a marked (irregular) form's morphosyntactic features is dependent on their verbal-memory skills.

Study 1 examined attributive adjective inflection in German which yields concatenated (stem+suffix) word forms to encode gender, number, and case features – a fully regular process without any lexical exception. In our priming experiment, we tested *-e, -s*, and *-m* forms of adjectives (e.g., *blaue, blaues, blauem* 'blue') as primes and targets and compared priming effects for different prime-target combinations, manipulating the relative degree of feature specification for the prime and target forms. We found longer RTs for highly specified and relatively infrequent

-m targets and – more interestingly – a priming asymmetry, such that prime-target combinations in which the target forms contained unprimed features produced less facilitation than prime-target combinations in which all of the target forms' features are already available from the prime (e.g., *blaue* → *blaues* vs. *blaues* → *blaue*). These findings indicate that our older participants benefitted from a prime word that was specified for a subset of the target's morphosyntactic features indicating sensitivity to connections between less-specified and more-specified forms. Study 2 examined inflected forms of verbs with marked (irregular) stems such as *wirf-* from *werfen* 'to throw', which are specified for morphosyntactic features (viz., tense, person, number). We again tested different prime-target combinations with respect to the relative degree of morphosyntactic feature specification for the prime and target forms. Our results in this study differed from those of Study 1 in that the priming asymmetry was modulated by participants' verbal memory skills. The greater a participant's CERAD Score (a composite of several subtests, the majority of which measured lexical access), the smaller the reductions of repetition priming for primes with marked stems and targets with unmarked stems, but not for the reverse case. That is, while in Study 1 a person's verbal-memory skill simply led to (marginally) faster RTs of all affixed forms across conditions, it had a more selective effect on lexically-conditioned morphological processing in Study 2.

Could the specific measures and the design of our experiments be responsible for these findings? Note that our design is unusual in that we compared priming patterns for morphologically related forms to a repetition condition rather than to unrelated controls (which is more commonly used). Feldman and Larabee (2001) presented data from two priming experiments, in which the same test items (e.g., *pay-payment* and *payable-payment*) were compared to an unrelated control condition (Experiment 1: crossmodal auditory-visual priming) and to an identity condition (Experiment 2: long-lag visual priming). The two types of test items showed the same amount of facilitation when compared to an identity condition, but differed in the amount of facilitation when compared to an unrelated condition. This pattern suggests that differences between different morphologically related prime types may be more difficult to detect when comparing morphological priming effects to an identity (rather than an unrelated) condition. Note, however, that even though we compared RTs for all our test conditions to the RTs of the corresponding identity conditions, we still obtained differences between test conditions. It is hard to see how any general issues with repetition priming can account for the condition differences we obtained.

The current results on morphological processing in older individuals, particularly the contrast obtained between accessing information from regularly affixed adjective forms versus finite verb forms of strong verbs with marked (irregular) stems, are reminiscent of the findings from our earlier study (Clahsen & Reifegerste, 2017), which tested a different inflectional process of German: past-participle formation. In this elicited-production study, older individuals' form-frequency effects for irregular participles were modulated by their CERAD Score (with lower scores leading to weaker frequency effects), the same measure that modulated the degree of facilitation from prime words with marked stems in the present study. By contrast, Clahsen and Reifegerste (2017) did not find any CERAD-based modulation of frequency effects for regular participles, similarly to the regularly affixed adjectives in Study 1 in the present paper.

These results can be explained in terms of the different linguistic properties of the phenomena involved. Consider first regular adjective and *-t* participle inflection that were found to be unaffected at old age. Both these phenomena involve rules of exponence that contain variables, that is, placeholders that stand for any member of a given category and directly spell out sets of features on these categories. For instance, the exponence rules for attributive adjective inflection directly spell out sets of case, number, and gender features on any member of the category [+ADJ(ective)]. Crucially, rules that contain variables are not lexically conditioned, that is, insensitive to the idiosyncratic properties of the tokens they instantiate. Hence, processing these forms engages grammatical computation but does not require any form-specific access to lexical memory beyond the retrieval of the base stem. By contrast, irregular participle forms and marked stems of strong verbs are lexically conditioned. Assuming structured entries such as those illustrated in Figure 1, irregular forms represent subnodes linked to the corresponding base form in which the subnode inherits all its properties and features from the base form except for the particular phonological changes and features it adds. Priming effects between lexically related items are thought to reflect reductions of activation thresholds, thereby facilitating target recognition. Consequently, the presentation of an inflected form containing a marked stem such as *wirf-* as a prime word is likely to co-activate its corresponding base stem entry, which should then facilitate the recognition of a target form that contains this particular stem entry. If, however, a person's relatively poor memory skill prevent her from fully accessing and processing the information contained in the subnode, this will result in less facilitation from the prime and, in turn, greater processing costs during the recognition of the target.

Our findings are also in line with previous research indicating a contrast between regular and irregular morphology in patients with pathological memory decline. Ullman et al. (1997) found people with Alzheimer's Disease to be impaired at producing irregular past-tense forms (compared to healthy controls), while their performance with regular past-tense forms was relatively preserved; but see Cortese, Balota, Sergent-Marshall, Buckner, and Gold (2006). Our results indicate that such a selective decline is not exclusive to pathological forms of memory decline, but seems to affect healthy aging as well. See also Birdsong and colleagues (Birdsong &

Flege, 2001; Birdsong, 2004, 2005) for a discussion of neuropsychological factors underlying such a dissociation.

One hypothesis addressing potential reasons for why older people struggle with certain aspects of language processing is the *transmission-deficit hypothesis* (MacKay & Burke, 1990; Burke & MacKay, 1997). This hypothesis states that older speakers possess weaker and less stable associative connections between representations in memory, which leads to less efficient transmission of information when these representations are accessed. This slow and error-prone transmission of information can then result in older people's difficulties at tasks requiring lexical access (Allen et al., 1991; Bowles & Poon, 1981; Mortensen et al., 2006, Newman & German, 2005). Previous research has indicated that these difficulties do not necessarily extend to computational processing, such as the processing of regular morphology or of simple syntactic structures, which are often found to be intact in older speakers (Clahsen & Reifegerste, 2017; Duñabeitia et al., 2009; Tyler et al., 2010). Our current findings are consistent with this account. Older speakers seem to be able to access morphosyntactic features contained in regular affixed forms regardless of their memory skills, but efficient feature access from lexically-conditioned (irregular) forms benefits from relatively good memory skills.

As an alternative to the transmission-deficit hypothesis, consider the possibility that slower response times at older age may not necessarily indicate cognitive decline. Ramscar, Hendrix, Shaoul, Milin, and Baayen (2014) argued that old age may lead to increased knowledge and experience, and – within language – to larger vocabularies. Consequently, lexical decision times may be longer for older than for younger adults, simply because it takes more time to search through a larger vocabulary. This may plausibly explain why our older speakers showed generally longer RTs than the student-age population reported in Clahsen et al. (2001) and in Krause et al. (2015). Our second main finding, however, that the efficiency with which older speakers deploy a marked (irregular) form's morphosyntactic features is dependent on their verbal-memory skills is hard to explain from this perspective. Another recent proposal (Moscoso del Prado Martín, 2017) holds that aging may affect the language processing abilities of women differently than those of men. Analyzing corpus data of dyadic interactions, Moscoso del Prado Martín (2017) found sex differences for syntactic diversity and number of dysfluencies (but not for lexical or inflectional diversity). While women's syntactic diversity and fluency increased across the lifespan, syntactic diversity and fluency in men peaked around the age of forty and then declined sharply. An exploratory analysis of our data revealed no interactions between sex and the critical effects for either of the two studies reported here (Study 1: PRIME AFFIX x TARGET AFFIX x SEX [releveled for s/ e]: $t = 1.54$; Study 2: PRIME TYPE x TARGET FORM x SEX: $t = 0.20$). Note, however, that less than a third of our participants were men as our study was not designed to address this question. Future studies should include a more balanced sex ratio as well as age as a continuous factor to explore the question of developmental trajectories of language processing across the lifespan more thoroughly.

Conclusion

While a lot of research has been devoted to the study of older people's cognition, considerably less is known about language processing, particularly grammatical processing, in older individuals. In the present study, we investigated the processing of inflected word forms in older individuals. The function of inflectional morphology is to realize or spell out grammatical features on different kinds of forms or exponents. Here we compared two exponent types, (i) regularly inflected (affixed) forms and (ii) irregular forms with lexically-conditioned stem variants. Previous experimental research indicated that younger adults efficiently access grammatical features from both these word forms during online word recognition. The main findings from the current study are that older individuals show efficient access of grammatical features from regularly inflected adjective forms, but that successful feature access from lexically conditioned (irregular) forms appears to depend on participants' verbal-memory skills, with better memory skills leading to more efficient feature access. In other words, direct access to the base stem through a form related to the base stem by a regular morphological process is unaffected at old age. On the other hand, aging does lead to a decline in irregular (lexically conditioned) indirect access of a stem – that is, activation of the base stem after viewing a lexically conditioned alternative stem form. At a more general level, our results are consistent with previous findings indicating a dissociation between lexically conditioned and lexically unconditioned grammatical processing in older individuals, who show greater difficulty with the former compared to the latter.

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