The more you know: Age-related facilitation in the production of irregular morphology

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Introduction

Dual Mechanism/Dual Route Models[1-4]**:** two routes for the processing of morphologically complex words.
- Regular forms: rule-based computation
- Irregular forms: retrieved from mental lexicon

Frequency effects as a diagnostic of storage[1]**:**
- Irregular forms are subject to frequency effects: faster reaction times (RTs) for high- vs. low-frequency forms.
- Regular forms generally show no frequency effects.

Declarative/Procedural (DP) model[3,4]

Learning, storage, and processing of language relies on:
- **Procedural memory (PM):**
  - Rule-governed aspects of language: combinatorial grammar, regular phonology
  - Morphology: regular forms
- **Declarative memory (DM):**
  - Idiosyncratic aspects of language: simple words, irregular phonology, idiosyncratic grammar
  - Morphology: irregular forms (and chunked (high-frequency) regular forms)

German Plurals

- German nouns take one of five plural affixes: *-Ø, -(e)n, -e, -er, -s*
- **Tripartite distinction**[1,2]**:**
  1) Default (lexically unrestricted):
     - *-s* (*Auto* → *Autos*, 'car'/'cars')
     - No frequency effects[5], stem priming effects[6]
     - ➢ Computed online: *Auto + -s*
  2) Non-default predictable (lexically restricted):
     - *-n* for feminine nouns ending in schwa (*Torte* → *Torten*, 'cake'/'cakes')
     - Frequency effects[5], stem-priming effects[5]
     - ➢ Stored with internal structure: *[{Torte}{-n}]*
  3) Non-default non-predictable (lexically restricted):
     - *-(e)n* for non-feminine nouns (*Name* → *Namen*, 'name'/'names') and non-schwa-final feminine nouns (*Oper* → *Opern*, 'opera'/'operas')
     - -er (*Geist* → *Geister*, 'spirit'/'spirit')
     - -e (*Tag* → *Tage*, 'day'/'days')
     - Frequency effects[5,7], no stem-priming effects[5]
     - ➢ Stored as full forms: *[Opern]*

Previous research on language and aging

Language processing
- Transformations of linguistic abilities (gains and losses)
- RTs: longer RTs across the board
- Accuracy: Mixed findings (declines, improvements, no changes), depending on task

Morphological processing
- Most research based on priming studies:
  - Regular forms: no changes in priming-effect size[8-12]
  - Irregular forms: priming effects decrease with age[8-10]
- One study[9] on frequency effects with only older adults:
  - Regular participles: No changes in frequency effect
  - Irregular participles: Size of frequency effect varied frequency effect size increased with increasing 'verbal memory' scores

➢ Selective effects of aging:
- Age-invariant (preserved) combinatorial processing
- Affected (declining?) storage-based processing

Research Question: *How does aging affect the production of morphologically complex words?*

Predictions:
- No frequency effects for default forms, independent of age
- Robust frequency effects for (both predictable forms and non-predictable)[5] non-default forms for younger speakers.
- Form-frequency effects for non-default plurals might be affected by age: decreasing form-frequency effect size with increasing age (e.g., due to age-related declines in memory skills)

Methods

Design PLURAL TYPE X FORM FREQUENCY X AGE

Participants 166 native German speakers without cognitive, neurological, psychiatric or language-related impairments

	20s	30s	40s	50s	60s	70s	80s	Effect of age
Count	41	37	18	27	26	11	6	
Sex	24 F, 17 M	21 F, 16 M	15 F, 3 M	20 F, 7 M	20 F, 6 M	5 F, 6 M	5 F, 1 M	$\chi^2(6, N=166)=15.50$, $p=.017$
Education	16.2 (2.2)	18.2 (3.5)	17.0 (3.5)	15.6 (3.4)	16.1 (3.0)	14.0 (2.0)	16.8 (3.4)	$r=-.15$, *ns*
Declarative Memory	0.66 (0.16)	0.70 (0.15)	0.63 (0.16)	0.50 (0.21)	0.53 (0.18)	0.35 (0.15)	0.46 (0.22)	$r=-.46$, $p<.001$
Procedural Memory	0.10 (0.09)	0.12 (0.10)	0.02 (0.04)	0.06 (0.09)	0.04 (0.06)	0.00 (0.06)	-0.01 (0.05)	$r=-.35$, $p<.001$
Working Memory	5.7 (1.2)	6.0 (0.9)	5.5 (0.7)	4.9 (1.0)	4.7 (1.0)	4.5 (0.7)	4.1 (1.0)	$r=-.49$, $p<.001$
Interference control	69 (28)	71 (27)	79 (33)	75 (40)	57 (31)	51 (23)	63 (31)	$r=-.08$, *ns*
Processing Speed	1093 (188)	1106 (188)	1400 (320)	1548 (314)	1921 (294)	2023 (231)	2106 (550)	$r=.73$, $p<.001$
ART	17 (9)	20 (10)	24 (9)	27 (10)	27 (12)	20 (9)	26 (7)	$r=.32$, $p<.001$

Note. Education: in years. Processing Speed: in ms (higher numbers = slower speed). ART: Author Recognition Test (number of correctly identified authors minus incorrectly selected foils; max = 50). Age binned for exposition only, analyses treat age as a continuous factor. Bin "80s" includes data from one 91-year-old participant.

Materials and tasks

Materials

140 German singular words:
- 120 target items from three different plural types:
  - 40 default plurals (*-s*)
  - 40 non-default predictable plurals (*-n*)
  - 40 non-default non-predictable plurals (10 *-er*, 30 *-n*)
- 20 filler items (*-e* plurals)

	Form frequency	Lemma frequency	Letter length	Syllable length	Phoneme length	Age of acquisition
Default	0.90 (0.92)	1.89 (1.48)	6.8 (1.7)	2.4 (0.7)	6.2 (1.5)	8.1 (2.6)
Non-default predictable	0.90 (0.93)	1.81 (1.31)	6.8 (1.2)	2.4 (0.6)	6.2 (1.1)	7.1 (2.4)
Non-default non-predictable	0.94 (0.94)	1.84 (1.56)	7.0 (1.5)	2.3 (0.5)	6.1 (1.4)	7.2 (2.1)

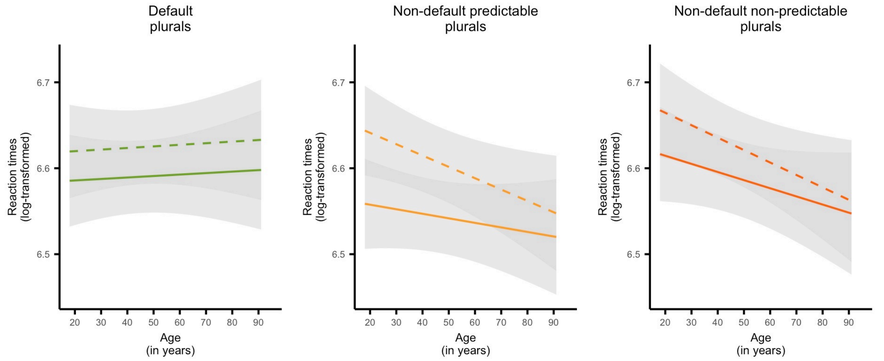
Note. Values refer to target-form properties. Frequency values: natural-log-transformed SUBTLEX-DE frequency[13]. AoA ratings: rating study (*n*=222, age range: 18-67 years).

Individual differences tests

1. Declarative memory: Incidental learning (deep encoding) and recognition of paired associates (depicted objects)[14]
2. Procedural memory: Serial Reaction Time (SRT) task[15]
3. Working memory: Corsi block-tapping task backwards[16]
4. Interference control: Eriksen Flanker task[17]
5. Processing speed: Pattern Comparison task[18]
6. Reading habits: Author Recognition Test (ART)[19]; list of author names and foils. Participants mark those they recognize.

Results

Analyses I: What is the pattern?



Note: Solid lines = high-frequency plural forms, dashed lines = low-frequency plural forms. Binary (median split) presentation for exposition only; analyses treat FORM FREQUENCY as a continuous factor.

- No significant main effects of AGE for any plural type (all *p*s>0.120).
- Various interactions involving factor PLURAL TYPE (AGE X PLURAL TYPE [default vs. non-default predictable], AGE X PLURAL TYPE [default vs. non-default non-predictable], AGE X FORM FREQUENCY X PLURAL TYPE [default vs. non-default predictable])

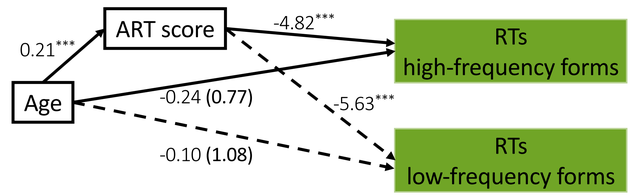
Default plurals
- Marginal frequency effect (*p*=.090).
- No interaction between AGE and FORM FREQUENCY
  - ➢ Marginal age-related increases in RTs, regardless of form frequency.

Non-default plurals
- Significant frequency effects (*p*s < .007)
- Significant interactions between FORM FREQUENCY and AGE (*p*s < .005):
  - ➢ Greater (numerical) age-related decreases in RTs for lower-frequency (vs. higher-frequency) forms.

Analyses II: What causes the pattern?

- Statistical tests of mediation[20-22]: R package "mediation"[23]
- Mediators tested:
  - Hypothesis-driven: DECLARATIVE MEMORY, PROCEDURAL MEMORY
  - Exploratorily: WORKING MEMORY, INTERFERENCE CONTROL, PROCESSING SPEED, READING HABITS (ART score)
- Nonparametric bootstrapping[23,24](1000 bootstrapped simulations)
- Only factor that showed mediation effects: READING HABITS (ART score)

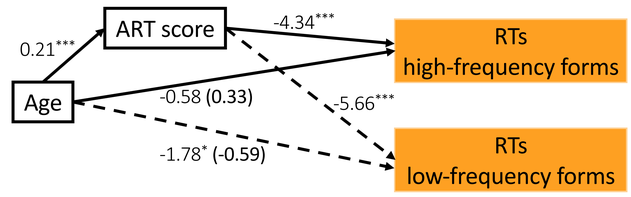
Default plurals:



Age → ART score → RTs (HF)
Indirect Effect:
β = -1.01, 95% CI [-1.73, -0.45]

Age → ART score → RTs (LF)
Indirect Effect:
β = -1.18, 95% CI [-2.00, -0.53]

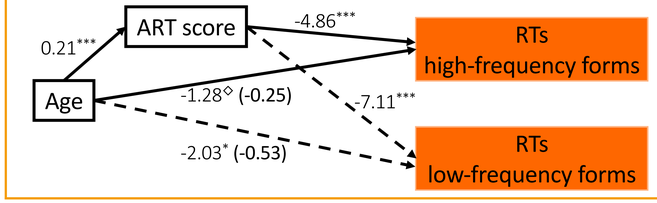
Non-default predictable plurals:



Age → ART score → RTs (HF)
Indirect Effect:
β = -0.91, 95% CI [-1.55, -0.41]

Age → ART score → RTs (LF)
Indirect Effect:
β = -1.18, 95% CI [-2.00, -0.53]

Non-default non-predictable plurals:



Age → ART score → RTs (HF)
Indirect Effect:
β = -1.02, 95% CI [-1.66, -0.46]

Age → ART score → RTs (LF)
Indirect Effect:
β = -1.49, 95% CI [-2.44, -0.75]

Discussion

What is the pattern?

Default versus non-default plurals:

Different processing patterns across participants:
- Default forms: Only marginal frequency effects
- Non-default forms: Pronounced form-frequency effects
  - ➢ Pattern suggests storage-based access of non-default (but not of default) forms

Age effects:

Selective age effects on regular versus irregular forms:
- Default forms:
  - Stable RTs and processing patterns across the lifespan
- Non-default forms:
  - Age-related RT *decreases*, especially for lower-frequency forms
  - Patterns held for predictable and non-predictable forms

What causes the pattern?

- ART scores (proxy for written language exposure) **mediate** effect of Age on RTs for low-frequency non-default forms.
  - ➢ Age-related speed-up might be due to greater experience with language.
  - ➢ Greater **cumulative frequency** of stored forms confers particular benefits at lower end of frequency continuum due to log-shaped effect of frequency on RTs.
- Combinatorial processes (that underlie default plural forms) seemed to be independent of language exposure.

Conclusion

- Different aging trajectories for default and non-default German plurals:
  - Default forms: Stable performance
  - Non-default forms: *Faster* responses with increasing age (especially for lower-frequency forms)
- Prolonged exposure to written language benefits the production of low-frequency non-default forms.

References & Acknowledgements

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