Appendix to 'When verbs have bugs: Lexical and syntactic processing costs of split particle verbs in sentence comprehension'

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ARTICLE HISTORY

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1. Traditional statistical analysis EEG

In this Appendix, we report an additional statistical analysis for the results of Experiment 3. The mean amplitudes in both selected time windows were analyzed with a repeated-measures ANOVA, using a subset of 48 electrodes grouped into regions of interest (ROIs).

Parametrization and statistical testing A subset of 48 electrodes was selected for the statistical data analysis. Electrodes were assigned to one of twelve regions of interest (ROIs), consisting of four electrodes each. ROIs were: left-posterior (O1, O9, P3, P7), left-posterior-medial (CP3, CP5, M1, TP7), left-anterior (AF3, AF7, F5, FT7), left-anterior-medial (C3, C5, FC5, T7), medial-posterior (Oz, PO1, PO2, Pz), medial-posterior-medial (CP1, CP2, CPz, Cz), medial-anterior (AFz, FP1, FP2, FPz), medial-anterior-medial (F1, F2, FCz, Fz), right-posterior (O10, O2, P4, P8),

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right-posterior-medial (CP4, CP6, M2, TP8), right-anterior (AF4, AF8, F6, FT8), right-anterior-medial (C4, C6, FC6, T8).

For each chosen time window, we performed a repeated measures ANOVA of the mean voltages in the selected ROIs, with within-subject factors CONDITION (with levels accusative, dative, intransitive and illegal) and ROI (with factors left-posterior, left-posterior-medial, left-anterior, left-anterior-medial, medial-posterior, medial-posterior-medial, medial-anterior, medial-anterior-medial, right-posterior, right-posterior-medial, right-anterior, right-anterior-medial). Based on our initial hypotheses, ANOVAs were run for each of the planned comparisons separately. Statistical analyses were performed in a hierarchical fashion, i.e., only statistically significant interactions were pursued. A Huyhn-Feldt correction was performed when the degree of freedom in the numerator was higher than 1. Original degrees of freedom and corrected probability levels are reported. Analyses were performed in R (R Core Team, 2017) using the ezANOVA function of the ez package (Lawrence, 2011).

1.1. Results

370-470 ms accusative vs. illegal: There was a statistically significant effect of CONDITION ($F(1{,}21)=10.22$, $p<.01$), and an interaction of CONDITION and ROI ($F(11{,}231)=2.97$, $\varepsilon=.25$, $p<.05$). The effect of CONDITION was statistically significant in the following ROIs: medial-posterior-medial ($t(20)=4.57$, $p<.001$), right-anterior-medial ($t(20)=2.56$, $p<.05$); marginal at medial-posterior ($t(20)=2.08$, $p<.06$)
accusative vs. intransitive: There was a statistically significant effect of CONDITION ($F(1{,}21)=6.34$, $p<.05$). Waveforms were more negative-going for intransitive than accusative conditions.
intransitive vs. illegal: There were no statistically significant differences between both conditions.
accusative vs. dative: There were no statistically significant differences between both conditions.

600-800 ms accusative vs. illegal: There was a statistically significant effect of CONDITION ($F(1{,}21)=11.02$, $p<.01$), of ROI ($F(11{,}231)=5.22$, $\varepsilon=.26$, $p<.01$), and an interaction of CONDITION and ROI ($F(11{,}231)=3.66$, $\varepsilon=.38$, $p<.01$). The effect of CONDITION was significant in the following ROIs: left-posterior ($t(21)=2.78$, $p<.05$), medial-posterior-medial ($t(21)=-2.72$, $p<.05$), right-posterior-medial ($t(21)=-2.16$, $p<.05$) and right-anterior-medial ($t(21)=-2.66$, $p<.05$) Waveforms were more positive-going for illegal than for accusative conditions.
accusative vs. intransitive: There was a statistically significant effect of ROI ($F(11{,}231)=3.76$, $\varepsilon=-24$, $p<.05$.

intransitive vs. illegal: There was a statistically significant effect of CONDITION ($F(1{,}21)=5.77$, $p<.05$) and of ROI ($F(11.231)=5.85$, $\varepsilon=.26$, $p<.01$).

accusative vs dative: There was a statistically significant effect of ROI ($F(11{,}220)=4.50$, $\varepsilon=.26$, $p<.01$). Waveforms for accusative and dative conditions ran closely parallel.

Taken together, the results of the analysis reported here match the results of the analysis reported in the main text for the outcome of Experiment 3. Both analysis find an enhanced N400 for both ungrammatical conditions compared to the accusative baseline condition, and no statistically significant difference between both enhanced N400s. In addition, neither the GAMM nor the ANOVA analysis suggest differences in the N400 time window for accusative and dative conditions. In the P600 time window, the findings for the accusative-illegal, intransitive-illegal and accusative-dative comparisons match the findings of the GAMM analysis: Both analyses find an enhanced P600 for illegal relative to accusative conditions, a difference between intransitive and illegal conditions, and no differences between dative and accusative conditions in this time window. The results for the accusative-intransitive comparison are slightly different depending on the analysis: Descriptively, we see an enhanced P600 in the intransitive compared to the accusative condition. Waveforms in this time window at central, left-central and right-central sites are more positive-going in the intransitive than in the accusative condition, but less so than the illegal condition. In the GAMM analysis reported in the main text, we find that the difference between accusative and intransitive is statistically significant in this time window. In the ANOVA analysis reported here, the contrast between accusative and intransitive does not reach statistical significance. The contrast between intransitive and illegal conditions remains statistically significant in both types of analysis.

For the interpretation of our results, this difference in statistical outcomes has the following consequences: Our GAMM analysis leads us to think that both intransitive and illegal conditions elicit an enhanced P600 relative to the accusative baseline, and that this P600 enhancenement is more pronounced in illegal than in intransitive conditions. Our ROI-based ANOVA analysis leads us to think that only illegal conditions elicit an enhanced P600 relative to the accusative baseline, and that the difference between illegal and intransitive conditions stems from an absent, rather than from a weaker, P600 effect for intransitives.

We assume that this small difference between the outcomes of our analyses reflects the fact that the GAMM analysis uses voltages from all available electrode sites, while the ROI-based ANOVA only uses means over selected electrode sites. This latter practice may make subtle contrasts stronger or weaker, depending on the contribution of individual electrodes to the overall effect. This leads us to think that our GAMM analysis is better suited to capture subtle differences between conditions, and in turn makes both positive and negative outcomes more reliable than a traditional ROI-based ANOVA analysis.

2. The GAMM model formula

The formula used in the GAMM models was

```
value ~ condition.ordered +
        neighbourhood.quad +
        s(X, Y) +
        s(X, Y, by = condition.ordered) +
```

```
s(X, Y, vp, bs = "fs", m = 1)
```

The meaning of the variables is explained as follows:

`value`**:** The mean potentials v_i at an electrode i for the respective time window, averaged over items for each participant.

`condition.ordered`**:** The condition coded as an ordered factor. This gives us the possibility to get differences between conditions modelled by difference smoothers, instead of one smoother per condition. In order to compute the planned comparisons, this variable can have two values A and B out of the overal four conditions `acc`, `dat`, `intr`, and `ill` in each model.

`neighbourhood.quad`**:** The weighted average

$$\bar{v}_i = \frac{\sum\limits_{j \neq i} v_j w_{ij}}{\sum\limits_{j \neq i} w_{ij}}$$

over all electrodes j other than i. For the weights we use a quadratic decaying functions of the Euclidean distance: $w_{ij} = 1/d_{ij}^2$

`X` **and** `Y`**:** The two dimensional coordinates of electrode i.

`vp` The participant ID.

Describing the terms:

`condition.ordered` We need this term just to account for the non zero average potential in both conditions.

`neighbourhood.quad` Adding the weighted average as fixed effect.

`s(X, Y)` The smoother in the first of the two conditions A and B. We use the simple spline based smoother set up by `s(...)`, since our variables X and Y are on the same scale.

`s(X, Y, by = bed.ordered)` This gives us the difference smoother between the conditions A and B.

`s(X, Y, vp, bs = "fs", m = 1)` codes per person random smoothers.

Table 1.: Electrode positions in 2 and 3 dimensions based on idealizations of the electrode layout. X_2, and Y_2 are the coordinates of the 2 dimensional projection used as predictors in the GAMM smoothers. X_3, Y_3, and Z_3 are coordinates in 3 dimensions used to compute the weighted average to account for the correlations between electrodes.

	electrode	X_2	Y_2	X_3	Y_3	Z_3
1	AF3	-0.25	-0.72	-0.38	0.85	0.10
2	AF4	0.25	-0.72	0.38	0.85	0.10
3	AF7	-0.58	-0.75	-0.71	0.71	-0.45
4	AF8	0.57	-0.74	0.71	0.71	-0.45
5	AFz	0.00	-0.77	0.00	0.93	0.10
6	C3	-0.41	-0.10	-0.72	0.00	0.57
7	C4	0.40	-0.11	0.72	0.00	0.57
8	C5	-0.60	-0.05	-0.93	-0.10	0.10
9	C6	0.61	-0.04	0.93	-0.10	0.10
10	CP1	-0.18	0.01	-0.34	-0.20	0.89
11	CP2	0.18	0.00	0.34	-0.20	0.89
12	CP3	-0.35	0.11	-0.60	-0.39	0.57
13	CP4	0.35	0.10	0.60	-0.39	0.57
14	CP5	-0.52	0.21	-0.81	-0.47	0.10
15	CP6	0.54	0.21	0.81	-0.47	0.10
16	CPz	0.00	0.11	0.00	-0.39	0.89
17	Cz	-0.01	-0.10	0.00	0.00	1.00
18	F1	-0.21	-0.48	-0.29	0.66	0.57
19	F2	0.19	-0.49	0.29	0.66	0.57
20	F5	-0.46	-0.54	-0.69	0.63	0.10

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	electrode	X_2	Y_2	X_3	Y_3	Z_3
21	F6	0.45	-0.56	0.69	0.63	0.10
22	FC1	-0.16	-0.23	-0.34	0.20	0.89
23	FC2	0.18	-0.23	0.34	0.20	0.89
24	FC3	-0.34	-0.31	-0.60	0.39	0.57
25	FC4	0.35	-0.33	0.60	0.39	0.57
26	FC5	-0.59	-0.31	-0.89	0.29	0.10
27	FC6	0.57	-0.31	0.89	0.29	0.10
28	FCz	0.00	-0.33	0.00	0.39	0.89
29	FP1	-0.32	-0.91	-0.37	0.93	-0.45
30	FP2	0.29	-0.92	0.37	0.93	-0.45
31	FPz	0.00	-1.00	0.00	1.00	-0.45
32	FT10	1.00	-0.30	0.89	0.16	-1.00
33	FT7	-0.76	-0.45	-0.93	0.37	-0.45
34	FT8	0.74	-0.46	0.93	0.37	-0.45
35	FT9	-1.00	-0.30	-0.89	0.16	-1.00
36	Fz	0.00	-0.54	0.00	0.72	0.57
37	Iz	0.00	1.00	0.00	-0.91	-1.00
38	LO1	-0.83	-0.76	-0.74	0.52	-1.00
39	LO2	0.83	-0.76	0.74	0.52	-1.00
40	M1	-0.98	0.17	-0.88	-0.23	-1.00
41	M2	0.99	0.18	0.88	-0.23	-1.00
42	O1	-0.31	0.72	-0.37	-0.93	-0.45
43	O10	0.42	0.91	0.38	-0.82	-1.00
44	O2	0.31	0.71	0.37	-0.93	-0.45
45	O9	-0.43	0.90	-0.38	-0.82	-1.00
46	Oz	0.00	0.77	0.00	-1.00	-0.45
47	P1	-0.20	0.28	-0.29	-0.66	0.57
48	P2	0.21	0.28	0.29	-0.66	0.57

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Table 1 – *Continued from previous page*

	electrode	X_2	Y_2	X_3	Y_3	Z_3
49	P3	-0.35	0.42	-0.55	-0.76	0.10
50	P4	0.36	0.41	0.55	-0.76	0.10
51	P7	-0.58	0.52	-0.71	-0.71	-0.45
52	P8	0.57	0.51	0.71	-0.71	-0.45
53	PO1	-0.14	0.54	-0.19	-0.91	0.10
54	PO10	0.77	0.61	0.69	-0.58	-1.00
55	PO2	0.13	0.54	0.19	-0.91	0.10
56	PO9	-0.77	0.60	-0.69	-0.58	-1.00
57	Pz	-0.00	0.35	0.00	-0.72	0.57
58	T7	-0.82	-0.12	-1.00	0.00	-0.45
59	T8	0.82	-0.11	1.00	0.00	-0.45
60	TP7	-0.76	0.24	-0.93	-0.37	-0.45
61	TP8	0.74	0.23	0.93	-0.37	-0.45

References

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