

Supplementary Materials for the manuscript, *When proactivity fails: An electrophysiological study of establishing reference in schizophrenia*

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1. Full ERP results for the effects of referential violation

These analyses contrasted the 1-referent matching pronouns with both the 1-referent mismatching and the 2-referent mismatching pronouns.

400-600msec: The results of the between-group omnibus ANOVAs are showed in Table S1. As shown Figure 3 (main manuscript), both the control and schizophrenia groups produced positivity effects in contrasting the 1-referent matching pronouns with both the 1-referent mismatching and the 2-referent mismatching pronouns. However, the scalp distribution of these positivity effects differed between the two groups (3-way interactions between Group, Sentence Type and Region in both ANOVAs). To further characterize the sources of these interactions, we examined these contrasts in each group separately.

The findings in the control group are summarized in Table S2. The positivity effect evoked by the 1-referent mismatching (versus the 1-referent matching) pronouns was widespread but larger at posterior regions (interactions between Sentence Type and Region in both mid-regions and peripheral ANOVAs; effects at central, parietal, and left posterior regions). The positivity effect evoked by the 2-referent mismatching (versus the 1-referent matching) pronouns was less widespread and had a left posterior focus (Sentence Type x Region interactions in both mid-regions and peripheral ANOVAs; significant effects in the left posterior region).

The findings in the schizophrenia group are summarized in Table S3. In people with schizophrenia, the positivity effect evoked by the 1-referent mismatching (versus the 1-referent matching) pronouns was anteriorly distributed (Sentence Type x Region interactions in mid-regions ANOVA; effects in prefrontal and frontal regions). The positivity effect evoked by the 2-referent mismatching (versus the 1-referent matching) pronouns had a more widespread distribution (effect of Sentence Type approached significance in mid-regions omnibus ANOVA).

600-800msec: As shown in Figure 3 (main manuscript), in both the control and schizophrenia groups, these positivity effects continued into this later time window (1-referent matching versus 1-referent mismatching: marginal main effect in mid-regions ANOVA: 1-referent matching vs. 2-referent mismatching: main effects in both the mid-regions and peripheral regions ANOVAs, see Table S1). Once again, the scalp distribution of these positivity effects differed between the two groups (3-way interactions between Group, Sentence Type and Region approaching or reaching significance in all ANOVAs, see Table S1). To further characterize the sources of these interactions, we examined these contrasts in each group separately.

The findings in the control group are summarized in Table S2. The late posterior positivity effect produced by the 1-referent mismatching (versus 1-referent matching) pronouns had a posterior, slightly left lateralized scalp distribution (interaction between Sentence Type and Region in the mid-regions ANOVA; interaction between Sentence Type, Region and Hemisphere in the peripheral regions ANOVA; effects in parietal and left posterior regions). The late posterior positivity effect produced by the 2-referent mismatching (versus 1-referent matching) pronouns also appeared to continue into this later window (interactions between Sentence Type and Region in both mid-regions and peripheral regions ANOVAs, although the positivity did not reach significance in any individual region). This contrast also evoked an anteriorly distributed and left-lateralized negativity effect (effects in prefrontal and left anterior regions).

The findings in the schizophrenia group are summarized in Table S3. The positivity effect evoked by the 1-referent mismatching (versus 1-referent matching) pronouns became more widespread in this time window (main effect of Sentence Type that approached significance at

the mid-regions ANOVA; effects in central and parietal regions). Similarly, the positivity evoked by the 2-referent mismatching (versus 1-referent matching) pronouns became more widespread in this time window (main effect of Sentence Type in both mid-regions and peripheral regions ANOVAs; effects that reached or approached significance at all except the prefrontal region). Unlike in controls, there was no hint of an anteriorly distributed negativity effect in either of these contrasts in this time window.

| | Effect | df | 400-600msec | | | | 600-800 msec | | | |
|----------------------------------|---------|--------|--|--------|--|-------|--|-------|--|-------|
| | | | 1-referent matching vs. 1-referent mismatching | | 1-referent matching vs. 2-referent mismatching | | 1-referent matching vs. 1-referent mismatching | | 1-referent matching vs. 2-referent mismatching | |
| | | | F | p | F | p | F | p | F | p |
| Mid-regions omnibus ANOVA | S | 1, 34 | 6.08 | 0.02* | 5.34 | 0.03* | 3.24 | 0.08^ | 4.14 | 0.05* |
| | SxG | 1, 34 | 0.08 | 0.78 | 0.99 | 0.33 | 2.20 | 0.15 | 5.26 | 0.03* |
| | SxRxG | 4, 136 | 4.56 | 0.01** | 3.46 | 0.03* | 1.67 | 0.19 | 3.95 | 0.02* |
| Peripheral regions omnibus ANOVA | S | 1, 34 | 2.27 | 0.14 | 4.35 | 0.05* | 2.75 | 0.11 | 6.23 | 0.02* |
| | SxG | 1, 34 | 0.01 | 0.91 | 2.13 | 0.15 | 0.64 | 0.43 | 6.05 | 0.02* |
| | SxRxG | 1, 34 | 7.60 | 0.01** | 4.95 | 0.03* | 1.18 | 0.29 | 4.46 | 0.04* |
| | SxHxG | 1, 34 | 0.72 | 0.40 | 3.40 | 0.07^ | 2.12 | 0.16 | 0.26 | 0.62 |
| | SxRxHxG | 1, 34 | 0.02 | 0.89 | 0.33 | 0.57 | 0.19 | 0.67 | 0.13 | 0.72 |

Table S1. Between-group analysis. Results of the mid-regions and peripheral regions omnibus ANOVAs showing effects of Sentence Type as well as interactions between Sentence Type and Group, Region, and/or Hemisphere in contrasting the 1-referent matching pronouns with the 1-referent and 2-referent mismatching pronouns in the 400-600msec and 600-800msec time windows. S = Sentence Type, G = Group, R = Region, H = Hemisphere. Significant effects are indicated using the following symbols: ^ $p < .10$. * $p < .05$. ** $p < .01$.

| | Effect | df | 400-600msec | | | | 600-800msec | | | |
|----------------------------------|--------|-------|--|----------|--|-------|--|--------|--|----------|
| | | | 1-referent matching vs. 1-referent mismatching | | 1-referent matching vs. 2-referent mismatching | | 1-referent matching vs. 1-referent mismatching | | 1-referent matching vs. 2-referent mismatching | |
| | | | F | p | F | p | F | p | F | p |
| Mid-regions omnibus ANOVA | S | 1, 19 | 3.72 | 0.07^ | 1.07 | 0.32 | 0.07 | 0.79 | 0.04 | 0.85 |
| | SxR | 4, 76 | 4.83 | 0.01** | 2.15 | 0.12 | 5.50 | 0.01** | 10.92 | 0.001*** |
| <i>Prefrontal</i> | S | 1, 19 | 0.36 | 0.56 | 0.22 | 0.64 | 2.53 | 0.13 | 5.27 | 0.03* |
| <i>Frontal</i> | S | 1, 19 | 2.23 | 0.15 | 0.54 | 0.47 | 0.54 | 0.47 | 2.44 | 0.14 |
| <i>Central</i> | S | 1, 19 | 5.66 | 0.03* | 1.85 | 0.19 | 0.79 | 0.39 | 0.04 | 0.84 |
| <i>Parietal</i> | S | 1, 19 | 13.81 | 0.001*** | 3.68 | 0.07^ | 6.31 | 0.02* | 1.50 | 0.24 |
| <i>Occipital</i> | S | 1, 19 | 0.03 | 0.86 | 0.32 | 0.58 | 0.33 | 0.57 | 2.81 | 0.11 |
| Peripheral regions omnibus ANOVA | S | 1, 19 | 1.54 | 0.23 | 0.29 | 0.60 | 0.67 | 0.42 | 0.00 | 0.98 |
| | SxR | 1, 19 | 12.90 | 0.01** | 6.20 | 0.02* | 8.96 | 0.01** | 23.21 | 0.001*** |
| | SxH | 1, 19 | 0.40 | 0.53 | 1.82 | 0.19 | 0.10 | 0.75 | 0.17 | 0.69 |
| | SxRxH | 1, 19 | 3.72 | 0.07^ | 2.68 | 0.12 | 5.05 | 0.04* | 1.01 | 0.33 |
| <i>Left frontal</i> | S | 1, 19 | 0.19 | 0.67 | 0.14 | 0.71 | 1.84 | 0.19 | 4.51 | 0.05* |
| <i>Right frontal</i> | S | 1, 19 | 0.04 | 0.85 | 0.25 | 0.62 | 0.02 | 0.88 | 1.85 | 0.19 |
| <i>Left posterior</i> | S | 1, 19 | 11.89 | 0.01** | 5.84 | 0.03* | 6.44 | 0.02* | 3.25 | 0.09^ |
| <i>Right posterior</i> | S | 1, 19 | 2.21 | 0.15 | 0.25 | 0.62 | 2.09 | 0.16 | 2.05 | 0.17 |

Table S2. Control group. Results of the mid-regions and peripheral regions omnibus ANOVAs showing effects of Sentence Type as well as interactions between Sentence Type, Region, and/or Hemisphere in contrasting the 1-referent matching pronouns with the 1-referent and 2-referent mismatching pronouns in the 400-600msec and 600-800msec time windows. Follow-ups of contrasts are also shown in individual regions.

| | Effect | df | 400-600msec | | | | 600-800msec | | | |
|----------------------------------|--------|-------|--|-------|--|-------|--|-------|--|----------|
| | | | 1-referent matching vs. 1-referent mismatching | | 1-referent matching vs. 2-referent mismatching | | 1-referent matching vs. 1-referent mismatching | | 1-referent matching vs. 2-referent mismatching | |
| | | | F | p | F | p | F | p | F | p |
| Mid-regions omnibus ANOVA | S | 1, 15 | 2.80 | 0.12 | 4.43 | 0.05^ | 3.76 | 0.07^ | 9.35 | 0.01** |
| | MxR | 4, 60 | 3.90 | 0.03* | 2.80 | 0.08^ | 1.46 | 0.25 | 2.46 | 0.12 |
| <i>Prefrontal</i> | S | 1, 15 | 7.31 | 0.02* | 4.26 | 0.06^ | 1.00 | 0.33 | 1.35 | 0.26 |
| <i>Frontal</i> | S | 1, 15 | 5.71 | 0.03* | 5.00 | 0.04* | 2.69 | 0.12 | 6.35 | 0.02* |
| <i>Central</i> | S | 1, 15 | 1.32 | 0.27 | 2.70 | 0.12 | 5.14 | 0.04* | 10.62 | 0.01* |
| <i>Parietal</i> | S | 1, 15 | 0.83 | 0.38 | 2.00 | 0.18 | 5.70 | 0.03* | 15.71 | 0.001*** |
| <i>Occipital</i> | S | 1, 15 | 1.39 | 0.26 | 0.39 | 0.54 | 0.61 | 0.45 | 5.02 | 0.04* |
| Peripheral regions omnibus ANOVA | S | 1, 15 | 0.86 | 0.37 | 4.33 | 0.06^ | 1.84 | 0.20 | 9.51 | 0.01** |
| | SxR | 1, 15 | 0.94 | 0.35 | 1.21 | 0.29 | 0.43 | 0.52 | 0.02 | 0.90 |
| | SxH | 1, 15 | 0.32 | 0.58 | 1.56 | 0.23 | 4.42 | 0.05 | 0.85 | 0.37 |
| | SxRxH | 1, 15 | 0.65 | 0.43 | 0.08 | 0.78 | 1.05 | 0.32 | 1.09 | 0.31 |
| <i>Left frontal</i> | S | 1, 15 | 0.51 | 0.49 | 2.89 | 0.11 | 0.00 | 0.96 | 4.38 | 0.05^ |
| <i>Right frontal</i> | S | 1, 15 | 1.45 | 0.25 | 3.37 | 0.09^ | 2.07 | 0.17 | 4.07 | 0.06^ |
| <i>Left posterior</i> | S | 1, 15 | 0.14 | 0.71 | 1.16 | 0.30 | 1.17 | 0.30 | 15.21 | 0.001*** |
| <i>Right posterior</i> | S | 1, 15 | 0.15 | 0.70 | 3.82 | 0.07^ | 3.53 | 0.08^ | 6.76 | 0.02* |

Table S3. Schizophrenia group. Results of the mid-regions and peripheral regions omnibus ANOVAs showing effects of Sentence Type as well as interactions between Sentence Type, Region, and/or Hemisphere in contrasting the 1-referent matching pronouns with the 1-referent and 2-referent mismatching pronouns in the 400-600msec and 600-800msec time windows. Follow-ups of contrasts are also shown in individual regions. S = Sentence Type, R = Region, H = Hemisphere. Significant effects are indicated using the following symbols: ^ $p < .10$. * $p < .05$. ** $p < .01$. *** $p < .001$.

2. Exploratory correlations between ERP effects of interest and WM span scores

Previous studies in young healthy adults have reported that individual behavioral measures of referential processing correlate with reading span measures (1), which, in part, tap into more general proactive control and working memory (WM) mechanisms (2). In addition, the magnitude of the Nref effect also correlates with reading span (3, 4). Finally, there is evidence that healthy individuals with low, but not high, reading spans produce late positivity effects, at least when the task encourages the establishment of referential coherence (see Experiment 1, (4)). In order to explore these relationships in the present study, we carried out correlations between reading span and ERP effects of interest in both the control and the schizophrenia groups. Note that, because of number of tests carried out, the relatively small sample sizes, and the restricted ranges in reading spans, these results should be considered preliminary.

Following (3, 4), we operationalized performance in the span task as the total number of words recalled. We correlated these scores with (a) the Nref effect evoked by the 2-referent matching minus the 1-referent matching pronouns between 400-600msec, averaged across left anterior electrode sites, F7, F3 and FC5, and (b) the positivity effects evoked by the 1-referent mismatching minus the 1-referent matching pronouns between 400-600msec and between 600-800msec, averaged across centro-parietal sites, Pz, CP1 and CP2.

We found no correlations between reading span scores and the magnitude of the Nref effect in either group (Pearson's $|rs| < .24$, $ps > .3$). We also found no correlations between reading span scores and the magnitude of the positivity effect between 400-600msec in either group (Pearson's $rs < .22$, $ps > .3$).

We did, however, see some evidence for associations between reading span scores and the magnitude of the late positivity effects evoked between 600-800msec in both the control and

schizophrenia groups. The direction of this association was different in the two groups. In the control group, the correlation was negative (Pearson's $r = -0.454$; $p < 0.04$): those participants with lower reading span scores produced a larger late positivity effect. This is consistent with previous work (Experiment 1: (4)). In the schizophrenia group, however, the correlation was positive: those participants with lower reading span scores produced a smaller late positivity effect (Pearson's $r = 0.51$; $p < 0.04$). While these findings should be considered primary, it is possible that this reflects a failure of those patients with particularly poor WM function to retroactively engage with context, leading to a failure to establish referential coherence altogether.

3. Exploratory correlations between ERP effects of interest and clinical measures within the schizophrenia group

Within the schizophrenia group, we also carried out post-hoc exploratory correlations between ERP effects of interest and various clinical measures: positive thought disorder, total SAPS, total SANS, duration of illness and chlorpromazine equivalents. Again, we correlated these measures with (a) the Nref effect evoked by the 2-referent matching versus the 1-referent matching pronouns between 400-600ms, averaged across left anterior electrode sites, F7, F3 and FC5, and (b) the positivity effects evoked by the 1-referent mismatching versus the 1-referent matching pronouns between 400-600ms and between 600-800ms, averaged across centro-parietal sites, Pz, CP1 and CP2. We found no significant correlations ($p > .08$).

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