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Discussion forum

On the left anterior negativity (LAN): The case of morphosyntactic agreement

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Molinaro, Barber, and Carreiras (2011) have proposed that the multidimensional linguistic nature of grammatical agreement can map onto specific modulations of early negativities around 300–400 msec [left anterior negativity (LAN)/N400] as well as the later P600. Tanner (2014) criticizes the reliability of the LAN as an ERP marker for studying grammatical agreement processing. We thank Tanner for his interest in our proposal and in this reply we consider separately four main arguments in this debate.

1. "LAN as an electrophysiological marker of morphosyntactic agreement processing"

Tanner's commentary starts from the above quote, illustrating the experimental starting point of our theoretical proposal (Molinaro, Barber, et al., 2011). Our view, however, is grounded in the correlational nature of ERPs: LANs are not exclusively triggered by grammatical agreement errors but also by other language-related manipulations (e.g., Molinaro, Canal, Vespignani, Pesciarelli, & Cacciari, 2013; Van Der Meij, Cuetos, Carreiras, & Barber, 2011). Consequently the LAN cannot be considered exclusively an *electrophysiological marker* of agreement. However, we maintain that the processes underlying the LAN are highly sensitive to mismatches of morphosyntactic features.

Furthermore, the LAN and N400 are not categorically distinct ERP components. On the contrary, the LAN/N400 topographical scalp distribution could reflect a continuum that can be very informative for research on agreement processing. Barber and Carreiras (2005) showed that the scalp distribution of LAN/N400 disagreement effects in Spanish word pairs varied depending on the grammatical class of the words involved. These results suggest that the more lexical-semantic information processed, the more N400-like are the effects observed in response to the agreement error (as also acknowledged by Tanner & Van Hell, 2014).

Thus, it is not surprising that Tanner and Van Hell (2014) observed N400 effects for subject-verb number agreement errors (e.g., *The clerk* <u>*at the clothing boutique*</u> *was/*were severely underpaid and unhappy*). In their stimuli the entire verb form varies and the agreement error is conveyed by the lexical (stem) alternation of *to be* verbs. LANs are typically observed in agreement studies of local syntactic relations (such as determiner-noun), while many semantic factors can influence subject-verb agreement processing (see Molinaro, Vespignani, et al., 2011). For example, intervening phrases (underlined in the above example) between subject and verb can interfere with agreement computation (see Martin, Nieuwland, & Carreiras, 2012).

2. Individual variability

Tanner presents some Montecarlo simulations claiming that the probability of sampling an N400 effect is much lower

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compared to the probability of sampling a P600 in a normal population. He claims that this N400/P600 imbalance would determine the "LAN-artifact" in the grand-average.

Research on individual differences analyzes the variance behind the average response of a population. From a quite different perspective, Molinaro, Barber, et al. (2011), Molinaro, Vespignani, et al. (2011) theoretical conclusions depend on the inferential power of the parametric statistics used across the studies reviewed. Such conclusions remain valid. In fact, if the LAN represents the average point of the variance with which a population responds to one linguistic manipulation and the N400 the average point of the variance with which the same population responds to a different linguistic manipulation, the conclusion that such a population differently processes the two linguistic stimuli is still guaranteed.

On the contrary, resampling methods have no inferential power. In fact, permutation approaches only allow conclusions about the sample of participants tested (in Tanner & Van Hell, 2014), but such conclusions cannot be extended to the general population (permutations are not inferential statistics). Critically, the sample studied by Tanner and Van Hell is not representative of the general population because they studied subject-verb number agreement errors (influenced by syntactic attraction) in American English speakers. Grammatical agreement, however, spans a larger set of linguistic dimensions that should not be underestimated.

Importantly, based on Tanner and Van Hell's (2014) observation of individual ERP differences, it would be interesting to understand what the sources of this variability are across participants. This could reflect differences in the brain structure of those participants (i.e., anatomical differences resulting in different scalp distributions) or differences in the processing strategy of each individual, or other cognitive factors. In addition, it could also be that variability across individuals is driven by "noise" signal variance across single trials. One way to test this would be to *statistically model such variability* in one single statistical model employing both fixed and random factors, using a mixed model procedure. Such an approach (with the selection of the correct measures for individual variability) would have high explanatory power, possibly opening up a field of research on the individual strategies behind language processing.

3. EEG reference

In Molinaro, Barber, et al. (2011), Molinaro, Vespignani, et al. (2011), we suggest that there are higher chances of observing a statistically reliable LAN effect in studies employing a hemisphere-independent reference (average activity of the two mastoids), compared to a lateralized reference (left mastoid). Tanner directly tested this claim (see Fig. 1 in Tanner, 2014) concluding that there is no substantial difference between an average reference (panel A) and a left mastoid reference (panel B). Unfortunately, Tanner did not report any *quantification* of this difference (magnitude of the effect or, more importantly, statistical evaluations) and it is thus hard to evaluate if there is any "substantial difference" for the two reference choices. Nonetheless, Fig. 1 in Tanner's paper shows that the LAN measured at F7 in panel A at least doubles the size of the same effect observed in the same electrode in panel B. We performed the same comparison as Tanner in one of our recent studies and observed a significant reduction in the amplitude of the LAN (Fig. 1 in the present paper).

4. Independence of (at least) two processing stages: LAN followed by P600

Tanner and Van Hell (2014) report an inverse correlation between N400 and P600. This would argue against the independence of LAN and P600 as evidence of two independent processing stages. However, this inverse correlation "emerges" from the data rather than being explanatory, since this study is not designed to functionally dissociate LAN/N400 and P600.

Mancini, Molinaro, Rizzi, and Carreiras (2011) designed a within-participant experimental contrast to differentiate the functional interpretation of the LAN-P600 biphasic response and observed that morphosyntactic mismatches that are grammatical in Spanish (Unagreement) elicited a left negativity (similar to Tanner & Van Hell, 2014), but no P600, while a similar manipulation that was ungrammatical did elicit the P600. This demonstrates that:

a) the LAN is not an artifact of the spatio-temporal overlap between N400 and P600, but an independent component that can be observed without P600 (as also recognized by Tanner in his *Summary and Discussion*);
b) the two components are functionally dissociable, with the early negativity reflecting increased cost of morphosyntactic processing and the P600 reflecting evaluation of a syntactic error.

This last study shows that the inverse relation between N400 and P600 cannot explain all the available data on ERP and agreement processing, but that probably the overall picture is much more complex, possibly involving several neurophysiological subcomponents. We do not claim that the brain performs *only two* operations during agreement processing (one represented by LAN/N400 and the second by P600), but we think that such ERP components can indeed be useful in studying grammatical agreement processing. We recently observed (Molinaro, Barber, Perez, Parkkonen, & Carreiras, 2013) that complex interactions across a large network of brain regions are involved in agreement processing before 500 msec and we aim to further investigate this complexity. In agreement with Tanner, we think it is very important to tackle the complexity behind individual differences: this is a fundamental domain that needs further research if we want language-related findings to have stronger explanatory power and be employed in teaching and clinical applications.

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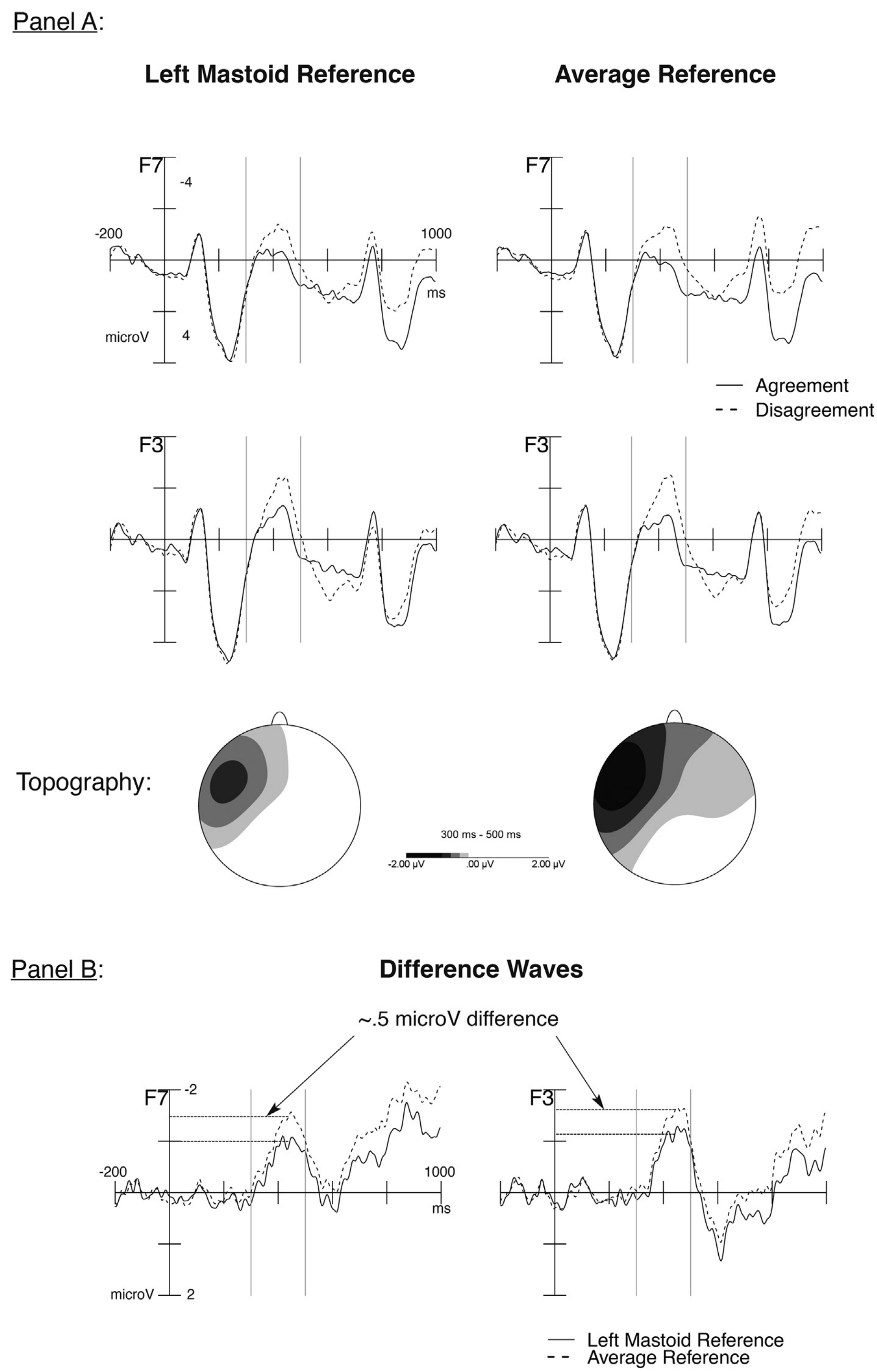

Fig. 1 – Left Anterior Negativity effect elicited by determiner-noun gender agreement errors (120 trials per condition) in a sample of 32 Spanish speakers. Here we report ERPs from two left-anterior representative electrodes. *Panel A*: ERPs elicted by agreement and disagreement in F7 (above) and F3 (below) when considering either the Left Mastoid reference (left column) or the Average reference (right column). Grey vertical lines indicate the LAN time interval. Below, we report the scalp topography of the differential effect (Disagreement – Agreement) in the 300–500 msec interval. *Panel B*: Difference waves (Disagreement – Agreement) in the same two electrodes reflect the reduction of around .5 μV of the LAN effect when using the Left Mastoid reference compared to the Average reference. In our sample this difference was significant when considering either F7 (Average Reference difference peak: −1.57 μV; Left Mastoid reference difference peak: −1.10 microV; $t(31) = 3.84$, $p < .01$), or F3 (Average Reference difference peak: −1.66 microV; Left Mastoid reference difference peak: −1.29 μV; $t(31) = 2.96$, $p < .01$), or a cluster of left-anterior electrodes (F7, F3, FC1, FC5, T7, C3: $t(31) = 3.42$, $p < .01$).

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