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Commentary

The CRITICAL DIFFERENCE in models of speech production: A response to Roelofs and Piai

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In our original article (Mahon, Garcea, & Navarrete, 2012), we replicated Dalrymple-Alford's (1972) observation of semantic facilitation at zero SOA when participants name the ink color (e.g., 'red') of semantically related non-color words (e.g., 'fire') compared to semantically unrelated non-color word distractors (e.g., 'lawn'; see also Glaser & Glaser, 1989). We replicated this classic finding to draw attention to the implications of this semantic facilitation effect, and semantic facilitation effects generally, for a model of word selection in speech production. The implication is straightforward: The theory of lexical selection by competition predicts that the distractor 'fire' should interfere more with saying 'red' than the distractor 'lawn'. This (and other) observation(s) of semantic facilitation are incompatible with the theory of lexical selection by competition. WEAVER++ (Roelofs, 1992, 2003) is the most developed model that implements lexical selection by competition, and as it makes both qualitative and quantitative predictions, its ability to simulate response time effects has been taken as a litmus test of the viability of the hypothesis of lexical selection by competition. As Roelofs and Piai (2013) write of the original (i.e., Roelofs, 2003) WEAVER++ simulations, "…facilitation of 41 msec or more was obtained at pre-exposure SOAs and no effect at zero SOA" (p. 1768).[1] In other words, the previously published simulations of WEAVER++ did not resemble, in relevant ways, the empirical data. On that basis, it seemed that WEAVER++ provided no special buoyancy to the theory of lexical competition. We argued, therefore, for a reweighting of the relative importance of semantic facilitation and interference effects in motivating models of lexical retrieval (for broader discussion, see Mahon, Costa, Peterson, Vargas, & Caramazza, 2007; Mahon et al., 2012; Navarrete, Del Prato, & Mahon, 2012; Navarrete & Mahon, 2013).

Roelofs and Piai (2013) highlight important issues that we overlooked in our original paper, and argue there is no reason to abandon the hypothesis of lexical selection by competition. The authors report a new simulation of WEAVER++ in which the value of the free parameter CRITICAL DIFFERENCE is adjusted so that the model is able to simulate the observed facilitation effects. The authors argue that the hypothesis of lexical competition, which is at the core of WEAVER++, is supported by these new simulations.

We believe that Roelofs and Piai (2013) arguments emphasize the wrong criteria for being satisfied with the performance of a computational model. The authors' criterion for being satisfied seems to be: if the model can simulate the effect in question, then that automatically, and without further justification, provides support for each of the component processes within the model. We disagree with that logic: what matter is not *that* WEAVER++ can explain semantic facilitation effects, but *how* the model explains those effects.

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[1] Roelofs and colleagues tend to emphasize 'facilitation' and 'interference' relative to a letter string baseline (compare Roelofs, 2003; Roelofs & Piai, 2013). However, what is relevant for evaluating whether lexical selection is a competitive process is whether the semantically related condition (response = red, distractor 'fire') is faster or slower than the semantically unrelated condition (response = red, distractor 'lawn').

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It is clear, from Roelofs and Piai's discussion that 'tuning' the free parameter CRITICAL DIFFERENCE effectively prevents lexical competition from making a significant contribution to RT variance.[2] But, if the way that WEAVER++ explains semantic facilitation is by reducing (or even eliminating) the connection between RT variance and lexical competition, then Roelofs and Piai have provided an existence proof for our conclusion—which was that semantic facilitation effects are incompatible with the assumption of lexical competition. Thus, demonstrations that WEAVER++ explains the data only when lexical competition is 'prevented' from affecting behavior, only further marginalizes the hypothesis of lexical competition. We first flesh out this argument and then return to the issues that Roelofs and Piai (2013) noted we overlooked.

1. The CRITICAL DIFFERENCE (or: lexical selection by threshold)

Because the original simulations of WEAVER++ did not explain semantic facilitation at zero SOA (see Fig. 22 in Roelofs, 2003), Roelofs and Piai (2013) report new simulations in which the value of the CRITICAL DIFFERENCE parameter is adjusted. "The simulations revealed that when the response-selection threshold (i.e., the critical difference in activation between target and competitors) in the model is increased somewhat (1.6 to 3.6), [or 125%], an associative facilitation effect of 27 msec is obtained at zero SOA." Roelofs and Piai conclude that this "…refutes the claim of Mahon et al. (2012) that 'the phenomenon can be explained only if one dispenses with the idea of competitive lexical selection' (p. 375 in Mahon et al., 2012 , p. 1768 in Roelofs and Piai)". But does it?

Unlike models of lexical selection designed to explain how the right word is selected (e.g., Dell, 1986), WEAVER++ stipulates which word is the target, and then explains *when* that target word is selected. Lexical selection in WEAVER++ involves two computational steps, as explained by Roelofs' (1992, p. 118) original description of the theory:

> "The determination of the response node is based on the *intersection* of the tag originating from the target source (e.g., the picture in picture naming) and a response-set flag on one of the lemma nodes. The node at which the intersection is established first will be the target lemma. … I will assume that an intersection is by itself insufficient to trigger a response. The activation level of the target lemma node must also exceed that of the other nodes in the response set by some critical amount [i.e., the CRITICAL DIFFERENCE]. Once this amount has been reached, the actual selection is a random event [modeled with the Luce choice ratio—i.e., lexical selection by competition]. … Thus, the probability of actually selecting the target lemma node depends on the activation state of other salient lemma nodes in the mental lexicon.[3] … When no intersection has been established and/or the CRITICAL DIFFERENCE has not been exceeded, then [the probability of selection equals zero]".

WEAVER++ has been widely adopted for its demonstrated ability to explain semantic interference in speech production. Since most discussion of WEAVER++ has been about its ability to explain interference effects, less attention has been paid to the computational step in the model that immediately precedes lexical selection by competition. However, the faster (i.e., fewer time steps) a target word takes to exceed the CRITICAL DIFFERENCE, the faster the system will advance to the stage at which selection is a probabilistic event modeled using the Luce choice ratio (i.e., lexical selection by competition). Thus, while the first step of lexical selection in WEAVER++ (i.e., the step at which the CRITICAL DIFFERENCE must be exceeded) has until now been a matter of peripheral interest, it turns out, according to Roelofs and Piai, to be critical in WEAVER++'s account of RT variance (see also Piai, Roelofs, & Schriefers, 2012).

As Roelofs and Piai (2013) argue, WEAVER++ can simulate the semantic facilitation effect at zero SOA by making the CRITICAL DIFFERENCE more conservative. That translates to ensuring that the model does not proceed to the second computational step of lexical selection (Luce ratio) unless the level of activation of the target far exceeds the levels of activation of 'competitors'. Hence, the probability estimate (hazard rate) computed at the second step is guaranteed to be comparatively high (numerator = activation of target; denominator = activation of nontargets). This means that there is little possibility of 'competition' at lexical selection modulating response times. What will matter are the relative levels of activation of the target in the different distractor conditions: "…with fire in red ink, the target response *red* is primed, whereas with lawn in red, the competitor [sic] *green* is primed" (Roelofs and Piai, p. 1768). The model is now functioning as a threshold model of lexical selection (for discussion on this point, see Piai, Roelofs, & Schriefers, 2012). Or, thought of differently, by increasing the CRITICAL DIFFERENCE, WEAVER++ effectively *dispenses* with competition as a mechanism that is contributing to RT variance.

A related issue, and to which Roelofs and Piai allude in the above excerpt, is the contribution of what Simon and Sudalaimuthu (1979) referred to as 'logical recoding' (for

[2] Absent in discussions of WEAVER++ (e.g., Roelofs & Piai, 2013) are tests of whether there *exist* common parameter values with which WEAVER++ is able to simulate *both* semantic facilitation and interference effects. Free parameter or not, if the CRITICAL DIFFERENCE is so critical for how the model explains RT effects (i.e., polarity shifts) then a proper treatment is warranted to test whether there are regions of the parameter space where the model can show both facilitation and interference. It should also be noted, that if the CRITICAL DIFFERENCE is in fact important for how the model behaves, then previous computational work (Roelofs, 2003) in which the CRITICAL DIFFERENCE took different values across different conditions within the same (simulated) experiment (see Roelofs, 2003; p. 125) may need to be revisited.

[3] Whether the denominator ranges over all activated words, all activated words that have been encountered as stimuli (targets or distractors) in the experiment, or only over items in the response set (i.e., targets) varies between Roelofs (1992), Roelofs (2003), and Roelofs and Piai (2013). We know (see Caramazza & Costa, 2000; 2001; Roelofs, 2001) that the original notion of a 'response set' restricting the words that can enter into competition is not viable.

discussion, see also Glaser & Glaser, 1989; Mahon et al., 2007). Logical recoding is the idea that the task performed on the target is automatically applied to the distractor. Thus, if the task is to 'extract' the target's ink color name, then that task would be applied to the distractors 'fire' and 'lawn'—eliciting the words 'red' and 'green', respectively. In that case, both a congruent response ('red') that is associated with fire, and an incongruent response ('green') that is associated with lawn are primed by the task. This raises the question, of whether the facilitation of 'fire' with respect to 'lawn', when both are in red ink, is *only* a facilitatory phenomenon or also has an interference component. We did not include a neutral word baseline in our replication of Dalrymple-Alford's study. The reason why we did not is because it was not necessary in order to evaluate the hypothesis of lexical competition, since that hypothesis predicts the more semantically similar distractor ('fire') should be slower than the more semantically distant distractor ('lawn') in naming the ink color red. As Mulatti and Coltheart (2012) discuss, Dalrymple-Alford (1972) observed both facilitation and interference referenced to the neutral word baseline. This would be an important issue to which to return with future empirical and computational work.[4]

But to return to the issue above, what does it *mean* for the 'response selection threshold' in WEAVER++ (i.e., CRITICAL DIFFERENCE) to be made more conservative? It means that a bias has been placed on which words will compete with the target in a way that can affect RT variance. An old idea (Lupker & Katz, 1981; see also Glaser & Glaser, 1989) that we and others (Kuipers, La Heij, & Costa, 2006; Mahon et al., 2007) have emphasized, is that there are task constraints that establish certain types of responses as appropriate. Roelofs and Piai invoke this notion of 'response relevance' in the context of WEAVER++ as justification for increasing the CRITICAL DIFFERENCE. While we are in agreement about the need to incorporate response relevant criteria into explanations of picture–word phenomena, it is not clear that WEAVER++ is the natural place to do so. If response relevant criteria have to be invoked *in any case*, why not just use them to explain semantic interference?

A more serious question is whether the implementation of response relevant criteria in WEAVER++ via the CRITICAL DIFFERENCE parameter is more than *ad hoc* fitting of the model to observations of semantic facilitation. Piai, Roelofs, and Schriefers (2012; p. 617) write:

> "According to the competition threshold hypothesis, distractors become competitors only if they receive enough activation to exceed the competition threshold. The function of such a threshold is to operate as an attentional filter (...), determining which elements will enter the competition space for response selection. (...) So, it is more beneficial if only the most plausible candidates enter the competition, and these candidates are those with a reasonably strong activation.

Is there a principled way to know when a distractor word should be considered to enter the 'competition space'? The criterion for deciding cannot be whether the distractor induces facilitation or interference empirically—if that were the case, then the model would be doing nothing more than fitting data *ad hoc*. This may boil down to a philosophical difference in how one views the contribution of a computational model. It is our view that at a certain point, it could become clear that a model is either no longer able to explain relevant phenomena, or that in order to 'make the model work', eccentric and *ad hoc* combinations of parameter values are required. We believe that the augments of Roelofs and Piai (2013) and Piai, Roelofs, and Schriefers (2012) and Piai, Roelofs, and Van der Meij (2012) signal that WEAVER++ is at that point. As such, the project of understanding how words are produced may be better served by removing the root cause of WEAVER++'s discomfort in explaining semantic facilitation: i.e., drop the assumption of lexical competition. That direction would represent an instance in which having a computational model allowed fine-grained adjudication between competing hypotheses: the performance of WEAVER++, together with the empirical facts, would be taken to demonstrate that the hypothesis of lexical competition is false. The alternative approach, which is the project of Roelofs and Piai's commentary, is to supplement WEAVER++ with additional processes in order to 'insulate' the problematic mechanism. This alternative, we would argue, puts the cart before the horse: it does not advance our understanding of how the speech production system works, but rather only shows how WEAVER++ can be saved.

The bottom line is that yes—WEAVER++ may be able to simulate semantic facilitation effects. But the mere fact that WEAVER++ 'works' is not what is relevant—what is relevant is *how* the model is able to simulate semantic facilitation. The way in which the model simulates semantic facilitation is by minimizing the contribution of lexical competition to RT variance: the model has been 'saved' by effectively capitulating its core mechanism. And thus, we would argue, Roelofs and Piai have tacitly provided an existence proof that semantic facilitation cannot be reconciled with the hypothesis of lexical selection by competition. Viewed in this way, the new simulations that Roelofs and Piai report are counterproductive to the authors' stated goal, which is to demonstrate that there is no need to give up on the hypothesis of lexical competition. In other words, "...semantic facilitation can be explained only if [WEAVER++] dispenses with the idea of competitive lexical selection" (p. 375 in Mahon et al., 2012 , p. 1768 in Roelofs and Piai)".

[4] It is not clear that the materials that Dalrymple-Alford used were matched for the kinds of variables that we now know must be matched in order to make comparisons across distractor conditions. Nevertheless, it is reasonable to assume that the related condition would be faster than a neutral word condition, because in both our experiment and in Dalrymple-Alford, the related condition (red-fire) was the same as a baseline of X's (and unrelated words interference more than Xs). Mulatti and Coltheart (2012) take a somewhat narrower view of the theoretical landscape in their comment. Our assumption (e.g., Mahon et al., 2012) with respect to the Response Exclusion Hypothesis, is that 'fire' and 'lawn' are equivalent in terms of exclusion time at the response buffer. The question could then be asked—what about the words 'red' and 'green', that are putatively covertly generated via logical recoding? Clearly, 'green' would incur a cost with the eventual response while 'red' would not. Thus, it may be important to direct future empirical work to test whether the difference between 'fire' and 'lawn' has both a facilitation and interference component.

An analogy captures what we think is wrong with Roelofs and Piai's (2013) core argument. Imagine the compass on a ship were broken, such that it correctly indicated north and south, but got east and west wrong. Imagine that the crew of the ship knew this, so that when they wanted to go north or south they looked at the compass, but when they needed to find east or west, they used the sun. Roelofs and Piai's argument is like the statement: "The compass must not be broken after all, because the ship always sails on course".

1.1. *Additional issues raised by Roelofs and Piai*

We also want to acknowledge Roelofs and Piai's (2013) valid points about the (overly)selective nature of our review of the previous literature, as it dealt with the evidence that has been marshaled both for and against the Response Exclusion Hypothesis. As they note, there have been important recent papers where a semantic interference effect is not observed in a delayed naming situation (Mädebach, Oppermann, Hantsch, Curda, & Jescheniak, 2011; Piai, Roelofs, & Schriefers, 2011), in contrast to the original report by Janssen, Schirm, Mahon, and Caramazza (2008). This is an important issue that requires further empirical work to resolve why the effect is observed in some situations and not others. But also noteworthy, Dhooge and Hartsuiker (2011) demonstrated distractor frequency effects in delayed naming—an observation that is problematic for lexical selection by competition, but predicted by the Response Exclusion Hypothesis (Mahon et al., 2007; see also the account of a Response Monitor by Dhooge & Hartsuiker, 2010; 2011; 2012). Limitations of space and scope prevent a more in depth treatment of these issues here, but it will be interesting to explore whether, and if so how, Roelofs and Piai's account is able to accommodate those data (Roelofs, 2005; Roelofs, Piai, & Schriefers, 2011).

Finally, Roelofs and Piai discuss EEG evidence that they argue supports an early (i.e., lexical) locus of semantic interference. Piai, Roelofs, and Van der Meij (2012) found that brain activity between 230 and 370 msec after picture onset indexes the semantic interference effect. Based on the meta-analysis of Indefrey (2011), Roelofs and Piai conclude that this electrophysiological evidence is congruent with WEAVER++ and challenges the Response Exclusion Hypothesis. But, other electrophysiological evidence seems, by the same logic, to be incompatible with WEAVER++. For instance, Dell'Acqua and colleagues found two ERP signatures of the semantic interference effect (using zero SOA) (Dell'Acqua et al., 2010). The first began at 106 msec, which is too soon for lexical selection. The second effect began at 320 msec, and thus fits well with the time window for lexical selection according to Indefrey (2011). Interestingly, Dell'Acqua and colleagues also found that an ERP component corresponding to phonological facilitation (i.e., faster naming times when the distractor word is phonologically related to the picture's name) was present in the same time window: 321 msec post picture onset. The fact that the ERP component corresponding to semantic interference was at the same latency as the ERP component corresponding to phonological facilitation raises difficulties for the view espoused by Roelofs and Piai, as its not clear how this would occur within the architecture of WEAVER++ (for different ERP semantic effects using picture–word paradigms, see Greenham, Stelmack, & Campbell, 2000; Hirschfeld, Jansma, Bölte, & Zwitserlood, 2008).

There are also ERP data that would seem to favor the Response Exclusion Hypothesis over WEAVER++. Dhooge, De Baene, and Hartsuiker (2013) reported ERP signatures of distractor frequency effects at three time windows: 20–60 msec, 420–500 msec and 520–580 msec. The first effect occurs too early to reflect language processes, and according to Dhooge and colleagues, may reflect differences in low-level visual features between high and low frequency distractor words. However, the time course of the latter two effects suggests a post-lexical locus for the distractor frequency effect, as predicted by the Response Exclusion Hypothesis, but difficult to reconcile with an input-level account as argued for by Roelofs (2005).

2. Conclusion

The theoretical advantage of dropping the assumption of lexical selection by competition, is that a simpler model can be adopted in which the highest activated word is selected. On this view, semantic facilitation, rather than semantic interference, is what should motivate a model of how words are retrieved from the mental lexicon. The very term 'lexical selection' is misleading, as it suggests conflict at the lexical level that does not exist—lexical 'retrieval' is a more accurate description of what occurs. The semantic interference effect, as observed in the picture–word and Stroop paradigms, is informative about post-lexical processes, for instance speech monitoring (e.g., Dhooge & Hartsuiker, 2012; Navarrete & Mahon, 2013). The upside of this approach is that it opens up a new set of questions about how to integrate models that have been developed to explain chronometric effects with models developed to explain error data (Dell, Oppenheim, & Kittredge, 2008).

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