Aspects of competition in word production: Reply to Mahon and Navarrete

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1. Introduction

A hotly debated issue concerning spoken word production is whether lexical selection is by competition or not. Recently, Mahon, Garcea, and Navarrete (2012) claimed that associative facilitation from color-related words in the Stroop task challenges lexical competition accounts of word production, such as implemented in the WEAVER++ model (e.g., Levelt, Roelofs, and Meyer, 1999; Roelofs, 1992). Associative facilitation concerns the finding that color naming (e.g., say “red”) is faster with associatively related words (e.g., the word *fire* in red ink color or combined with a red rectangle) than with unrelated words (e.g., *lawn*). However, in a comment (Roelofs and Piai, 2013), we demonstrated through WEAVER++ simulations that associative facilitation is fully compatible with a lexical competition account. In a response to our comment, Mahon and Navarrete (2014) argued that these simulations are problematic and that recent event-related brain potential (ERP) data provide evidence against lexical selection by competition.

In the present article, we first briefly discuss the associative facilitation in the Stroop task and our demonstration by computer simulations that the facilitation is fully compatible with a lexical competition account of word production (Section 2). Next, we argue that the rejection of this demonstration by Mahon and Navarrete (2014) is based on a mischaracterization of the competition account and its computational implementation in WEAVER++ and other models in the literature. We make clear what competition models really maintain and how competition is computationally implemented in these models, and we show that under the correct interpretation of what competition entails in these models, the rejection of lexical competition by Mahon and Navarrete is unwarranted (Section 3). Moreover, we argue that evidence on the time course of Stroop interference challenges the response-exclusion account advanced by Mahon and Navarrete (Section 4). Finally, we argue that the recent ERP findings are compatible with lexical competition models, again contrary to what Mahon and Navarrete claim (Section 5).

2. Associative facilitation and lexical competition

In a seminal study of the effect of associative relatedness in the Stroop task, Dalrymple-Alford (1972) obtained a facilitation effect of 85 msec in naming ink colors. Moreover, Glaser and Glaser (1989, Experiment 5) obtained an associative facilitation effect of 27 msec or more in naming color rectangles when the related and unrelated words were preexposed (e.g., by 100, 200, or 300 msec) and a facilitation effect of 13 msec (significance unknown) at zero stimulus onset asynchrony (SOA). In WEAVER++ simulations run by Roelofs (2003), facilitation of 41 msec or more was obtained at word preexposure SOAs and no effect at zero SOA. The facilitation effect at preexposure SOAs in the model clearly shows that associative facilitation is compatible with lexical competition. 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).

Still, although the absence of facilitation in the model at zero SOA is close to the 13 msec effect of Glaser and Glaser (1989), it does not agree with the facilitation that Dalrymple-Alford (1972) observed at this SOA. Therefore, in our comment on Mahon et al. (2012), we reported on our exploration of whether facilitation may be obtained at zero SOA in WEAVER++ (Roelofs and Piai, 2013). Our simulations revealed that when the lexical competition is somewhat increased by increasing the response-selection threshold (i.e., the critical difference in activation between target and competitors) in the model (from 1.6 to 3.6), an associative facilitation effect of 27 msec is obtained at zero SOA. This corresponds well to the 19 msec facilitation obtained by Mahon et al. (2012) in their own experiment. The facilitation in the simulations concerned the difference in effect between associatively related words (e.g., *fire* combined with a red rectangle) and unrelated words (e.g., *lawn* combined with a red rectangle), contrary to the inaccurate suggestion by Mahon and Navarrete (2014) that we “tend to emphasize ‘facilitation’ and ‘interference’ relative to a letter string baseline” (p. 123). Importantly, the tuning of the critical difference parameter (i.e., the increase from 1.6 to 3.6) does not determine whether associative facilitation or interference will be obtained, contrary to what Mahon and Navarrete incorrectly suggest in their response. Rather, it determines whether facilitation will be obtained at word preexposure SOAs only or, in addition, also at zero SOA. Moreover, the parameter tuning concerned a small change rather than supplementing “WEAVER++ with additional processes” (p. 125) as Mahon and Navarrete suggest.

3. Critical difference and Luce ratio

In their response, Mahon and Navarrete (2014) reject the counterarguments presented in Roelofs and Piai (2013) by saying that “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. 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.” (p. 124) However, the opposite is true: Facilitation appeared in the model at zero SOA and not only at preexposure SOAs exactly because we *increased* rather than reduced or eliminated lexical competition. Mahon and Navarrete incorrectly equate competition in WEAVER++ with the Luce ratio, whereas competition in the model has always been determined by two aspects, namely by the critical difference and the Luce ratio.

As described extensively in earlier articles, competition in lexical selection in WEAVER++ involves two phases (e.g., Levelt et al., 1999; Roelofs, 1992, 2003). In the first phase, the activation of a target should exceed the activation of competitors by a critical amount: the critical difference. In the second phase, the actual selection of the target is a random event, whose probability is determined by a ratio of the activation of target and competitors. We discuss these phases in more detail below.

First, the activation of a target lexical item should exceed that of competitors by a critical difference. This aspect of the competition process in WEAVER++ is shared with other implemented lexical competition models in the literature such as the model of La Heij and colleagues (Bloem and La Heij, 2003; Starreveld and La Heij, 1996). As Starreveld and La Heij (1996) stated, “Selection takes place when the activation of a phonological node exceeds that of all other phonological nodes by some critical amount *c* (see Roelofs, 1992a, for a selection mechanism that incorporates a similar parameter). If the selection process is more difficult, the selection will take more iterations, and the simulated RT will be longer.” (p. 904) In WEAVER++ and the model of Starreveld and La Heij, processing happens in discrete time steps. On every time step, activation spreads from node to node in a lexical network. Assume that the color of the word *green* in red ink has to be named (say “red”). In the simulations, the corresponding concept node (for the red ink) and word node (for the word *green*) receive external activation. Activation then spreads through the network with each node sending a proportion of its activation to connected nodes. As a result, the word nodes of *red* and *green* become activated. The word node for *red* will only be selected if its level of activation exceeds that of competitors (e.g., *green*) by a critical amount. It will take more time steps before this critical difference in activation between target and competitors is reached in the incongruent Stroop condition (e.g., *green* in red ink) than in a control condition (e.g., consisting of a series of Xs in red ink), because the activation of competitor word nodes will be boosted by incongruent words (e.g., *green*) but not by Xs. Moreover, as the WEAVER++ simulations of Roelofs (2003) and Roelofs and Piai (2013) showed, it takes fewer time steps before the critical difference is reached with associatively related words (e.g., *fire* in red ink) than unrelated words (e.g., *lawn* in red ink): the associative facilitation effect.

Second, once the critical difference in activation has been reached in WEAVER++, the actual selection of the target lexical item at a particular moment in time is a random event, whose probability is determined by the Luce ratio (i.e., the activation of the target divided by that of the sum of the activation of the competitors and the target itself). The higher the activation of competitors, the longer it takes before the target is actually selected. This second aspect of competition is not part of the model of La Heij and colleagues. So, the speed of selection of the target lexical item in WEAVER++ depends in two ways on the activation level of competitors, namely through the critical difference and the Luce ratio.

However, contrary to this, Mahon and Navarrete (2014) erroneously do not take the exceeding of the critical difference to be part of the competition process. They stated, “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).” But this incorrectly characterizes the competition process in WEAVER++ as well as in the model of La Heij and colleagues, where the critical difference has always been at the heart of the competition process. In fact, if one would take the critical difference not to be part of the competition process, then the model of La Heij and colleagues would not be a competition model at all (since it does not use a Luce ratio), contrary to what La Heij and colleagues have argued in several articles (e.g., La Heij, Kuipers, and Starreveld, 2006; Starreveld and La Heij, 1996) and to what is maintained by Mahon and colleagues themselves. They stated, in these models “the time required to select the target word is affected by the levels of activation of nontarget words (La Heij, 1988; Levelt, Roelofs, & Meyer, 1999; Roelofs, 2003). This hypothesis is referred to as lexical selection by competition. The hypothesis of lexical selection by competition states that the time required to select the target word increases as the levels of activation of nontarget words increase” (p. 503).

The common way in which lexical competition happens in the competition models (i.e., shared by WEAVER++ and the model of La Heij and colleagues) is through the requirement that the target exceeds a critical difference in activation relative to competitors. The critical difference is at the heart of competition models rather than an aspect of these models of “peripheral interest” (Mahon and Navarrete, 2014, p. 124). Moreover, contrary to the suggestions by Mahon and Navarrete, it is important to distinguish the critical difference and the notion of a competition threshold that has recently been proposed by Piai, Roelofs, and Schriefers (2012), which is not part of WEAVER++. The critical difference concerns the difference between target and competitors, whereas the competition threshold concerns *which* items will be competitors.

Despite the demonstrations by Roelofs (2003) and Roelofs and Piai (2013) that WEAVER++ accounts for the associative facilitation in the Stroop task, Mahon and Navarrete (2014) still maintain incorrectly that the finding is incompatible with the competition assumption of the model. However, Roelofs (2003) already showed that associative facilitation occurs at word preexposure SOAs in the model, and Roelofs and Piai (2013) showed that facilitation occurs at zero SOA when competition in somewhat increased. The account of facilitation at word preexposure SOAs is important because models of Stroop task performance should not only be able to explain effects at zero SOA but also at other SOAs. However, Mahon and Navarrete concentrate only on zero SOA, thereby overlooking that associative facilitation did occur in earlier simulations using WEAVER++ (Roelofs, 2003) and that the facilitation is thus compatible with lexical competition.

4. Time course of Stroop interference

Importantly, by concentrating only on zero SOA, Mahon and Navarrete (2014) missed the fact that the SOA findings on Stroop interference of Glaser and Glaser (1989, Experiment 5) challenge their response-exclusion account. This account holds that interference arises when a motor program for the distractor word needs to be removed from an articulatory buffer. At preexposure SOAs, incongruent color words (e.g., *green* combined with a red rectangle) yield Stroop interference in color naming. The mean color naming RT in the control condition of Glaser and Glaser was about 500 msec. Based on the estimations of Indefrey and Levelt (2004; Indefrey, 2011), the articulatory buffer is estimated to be reached no earlier than about 145 msec before articulation onset (see Roelofs, 2014, for extensive discussion). For the study of Glaser and Glaser, this would mean that the articulatory buffer is reached no earlier than about 500 – 145 = 355 msec after color onset. This entails that under the response-exclusion account of the interference effect at a word preexposure SOA of 300 msec, the motor program for the word should still not have been removed from the buffer at 300 + 355 msec = 655 msec after word onset. Similarly, in seminal SOA studies of Stroop task performance, Glaser and Glaser (1982, Experiment 1) obtained Stroop interference at a preexposure SOA of 300 msec. The same has been obtained more recently by Roelofs (2010a). Moreover, Roelofs (2010b) obtained Stroop interference at a preexposure SOA of 400 msec, with a mean naming RT of about 600 msec. Under the response-exclusion account, the latter finding entails that the motor program for the word is still not removed from the articulatory buffer at about 400 + 455 msec = 855 msec after word onset. The 655 and 855 msec estimates for response exclusion are much longer than the 200 msec proposed by Dhooge and Hartsuiker (2010), who stated "responses to distractors can be removed as early as 200 ms after presentation" (p. 887). This conclusion holds even when adding 100 msec for the Stroop effect itself to the estimate of 200 msec. To conclude, extant RT findings on the time course of the Stroop interference effect challenge the response-exclusion account.

5. ERP evidence on distractor effects

At the end of their response, Mahon and Navarrete (2014) discuss ERP data that they take to be problematic for WEAVER++. First, Dell'Acqua et al. (2010) obtained semantic and phonological effects of distractor words in picture naming in overlapping ERP time windows. This is contrary to WEAVER++, where the onset of semantic effects should precede the onset of phonological effects because semantic effects occur in lexical selection and phonological effects during phonological encoding. However, Mahon and Navarrete do not acknowledge that these findings of Dell'Acqua et al. are also problematic for their response-exclusion account, where phonological effects should precede semantic effects, because phonological effects occur during lexical access and semantic effects during articulatory buffering according to this account (see Piai, Roelofs, and Schriefers, 2014, for an extensive discussion). Moreover, the ERP findings of Dell'Acqua et al. challenge the theory of Dell'Acqua, Peressoti, and Pascali (2007), which holds that semantic interference arises during conceptualization processes (i.e., preceding lexical access), whereas phonological effects occur during lexical access itself. Thus, the ERP findings of Dell'Acqua et al. are problematic for all theories of word production. Given that the ERP findings of Dell'Acqua et al. have not been replicated yet, we believe that it is premature to draw any strong theoretical conclusions based on these findings, as Mahon and Navarrete do.

Second, Mahon and Navarrete (2014) argue that the ERP findings on the distractor frequency effect of Dhooge, De Baene, and Hartsuiker (2013) challenge WEAVER++. Dhooge et al. examined the time course of the distractor-frequency effect in picture naming: Low-frequency distractor words yield longer naming RTs than high-frequency distractors. They observed an ERP effect for low- versus high-frequency distractors between 420 and 500 msec and between 520 and 580 msec post picture-word onset. According to Dhooge et al., these ERP effects occur too late for WEAVER++ and thus support the response-exclusion account. But is this conclusion really warranted?

It is important to note that competition in WEAVER++ not only occurs in lexical selection but also in the selection of motor programs (i.e., during phonetic encoding, *before* articulatory buffering), see Roelofs (1997, 2010a, 2014) and Levelt et al. (1999). Lexical selection is the relevant level for the issue of the locus of semantic interference (semantically related vs. unrelated words), but for the distractor-frequency effect, both lexical selection and motor-program levels matter. In WEAVER++, low-frequency distractors are processed longer (i.e., they are blocked out later) than high-frequency distractors and therefore induce more competition at the lexical selection and phonetic encoding levels (cf. Roelofs, 1997; Roelofs, Piai, and Schriefers, 2011). Indefrey and Levelt (2004; Indefrey, 2011) provided estimates for the onsets of lexical selection and phonetic encoding, namely at about 200 msec and about 455 msec post picture/color onset, respectively. However, the estimates of Indefrey and Levelt were based on a mean naming RT of about 600 msec, whereas Dhooge et al. (2013) observed a mean RT of 780 msec. For rescaling the estimates in case of longer mean RTs, there are a number of options (Indefrey, 2011).

The most straightforward procedure would be a linear rescaling of all stage durations. With linear rescaling, the onsets of lexical selection and phonetic encoding in Dhooge et al. are estimated to occur at about 260 and 592 msec post picture-word onset, respectively. The articulatory buffer is reached after 592 msec because phonetic encoding needs to be completed before the motor program can enter the buffer. Another option would be to rescale only some rather than all of the stage durations, based on assumptions about the details of the experimental situation. For picture naming tasks with visual distractor words, it is plausible to assume that early visual processing is more difficult with than without distractors. This would entail that only the duration of early visual lead-in processes has to be rescaled rather than the duration of all processing stages. With lead-in rescaling, the onsets of lexical selection and phonetic encoding in Dhooge et al. are estimated to occur at about 380 and 635 msec post picture-word onset, respectively. Again, the articulatory buffer is reached after 635 msec because phonetic encoding still has to be completed. Thus, the distractor-frequency effect (reflected in the ERPs between 420 and 500 msec and between 520 and 580 msec post picture-word onset) occurred in the time window of word planning (i.e., 260-592 or 380-635 msec) rather than articulatory buffering (after 592 or 635 msec), regardless of the type of rescaling, contrary to the claims of Dhooge et al. and Mahon and Navarrete (2014).

Nonetheless, Dhooge et al. (2013) took their ERP findings as evidence against the lexical competition account and in favor of the response-exclusion account. However, even without any rescaling, the ERP evidence of Dhooge et al. does not agree with the response-exclusion account, which holds that the distractor-frequency effect should not occur earlier than about 145 msec before articulation onset. That is, the ERP effect should not occur earlier than about 635 msec post picture-word onset, whereas the effect was observed before 580 msec. In contrast, the findings of Dhooge at al. agree with WEAVER++'s assumption that the distractor-frequency effect arises during word planning, which is also supported by other EEG and MEG evidence on the time course of semantic and Stroop-like effects of distractor words in picture naming (e.g., Piai, Roelofs, and Van der Meij, 2012; Piai, Roelofs, Jensen, Schoffelen, and Bonnefond, 2014).

It should be noted that cognitive processes usually have a random component that influences their duration. The process duration on a particular trial typically will be shorter or longer than the mean duration across trials. This holds for both RT and ERP data. Thus, the time estimates figuring in the argumentation of Dhooge et al. (2013) and above should be seen as approximations. Still, these approximations suggest that extant ERP findings are more compatible with the lexical competition than with the response-exclusion account.

6. Summary and conclusion

To recapitulate, we argued that Mahon and Navarrete (2014) incorrectly excluded the critical difference from the competition process in WEAVER++ and the model of La Heij and colleagues. Associative facilitation appeared in the WEAVER++ simulations of Roelofs and Piai (2013) at zero SOA and not only at preexposure SOAs because we *increased* rather than reduced or eliminated lexical competition, contrary to what Mahon and Navarrete maintain. Moreover, extant electrophysiological evidence on distractor effects in word production is either incompatible with all theories in the literature or specifically supports the competition account, again contrary to what Mahon and Navarrete maintain. Thus, whereas the response-exclusion hypothesis meets with theoretical and empirical difficulty (e.g., Aristei and Abdel Rahman, 2013; Abdel Rahman and Aristei, 2010; Abdel Rahman and Melinger, 2009; Hantsch and Mädebach, 2013; La Heij, Kuipers, and Starreveld, 2006; Mädebach, Oppermann, Hantsch, Curda, and Jescheniak, 2011; Mulatti and Coltheart, 2012, 2014; Piai et al., 2011, 2012, 2014; Roelofs and Piai, 2013; Roelofs et al., 2011, 2013; Sailor and Brooks, 2014; Starreveld, La Heij, and Verdonschot, 2013), the competition hypothesis remains a viable account of word selection in word production.

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