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Commentary

The observed locus of semantic interference may not coincide with the functional locus of semantic interference: A commentary on Shitova et al.

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In a recent issue of *Cortex*, Shitova and colleagues (Shitova, Roelofs, Schriefers, Bastiaansen, & Schoffelen, 2017) addressed how congruency effects in a picture-word interference task (e.g., that a picture is named faster if the same word is shown) are reduced following incongruent trials (e.g., when a picture needs to be named while another word is shown) compared to congruent trials (e.g., a picture with the same word). A hotly debated topic in psycholinguistics (Dell'Acqua, Job, Peressotti, & Pascali, 2007; Fagot & Pashler, 1992; Piai & Roelofs, 2013; Schnur & Martin, 2012; Van Maanen & Van Rijn, 2010; Van Maanen, Van Rijn, & Taatgen, 2012) is whether this Gratton effect (Gratton, Coles, & Donchin, 1992) in picture naming (Lupker, 1979) is driven by phonological, lexical, or semantic differences between stimuli. As phonological, lexical and semantic information is activated in a partially overlapping temporal sequence, this question can be rephrased as identifying the temporal locus of the Gratton effect. Shitova and colleagues specifically asked the question whether a slowing down of responses in a picture-word interference paradigm following incongruent trials was caused by increased lexical or increased semantic interference due to the congruency of the previous trial.

In arguing for this study, the authors extensively discuss our paper *The locus of the Gratton effect in picture-word interference* (Van Maanen & Van Rijn, 2010), which addresses related questions. In the current commentary, we would like to clarify some confusion and misconceptions that seem to have influenced Shitova et al.'s discussion of their results in relation to our previous findings.

The Gratton effect refers to the finding that interference – typically measured as response time differences between the

different congruency conditions – is decreased following a trial that induces increased cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gratton et al., 1992). Such increased cognitive control may be exerted by, for example, incongruent trials in picture-word interference experiments (Shitova et al., 2017; Van Maanen & Van Rijn, 2010). The perceived difficulty during an incongruent trial may result in a more conservative response mode on a subsequent congruent trial, resulting in relatively slower responses in that condition. As Shitova et al. point out, although this effect is commonly observed in psycholinguistic studies, the question what stage of the cognitive process – the temporal locus – causes increased response times is usually not considered.

In our previous work, we applied a Psychological Refractory Period (PRP, Fig. 1) experimental design (Pashler, 1994) to address the question of the locus of the Gratton effect. PRP experiments typically consist of two parallel tasks. Both tasks are assumed to require access to a central cognitive resource, which forces a delay in task execution, since the central cognitive resource is only available for one task at the time. The rationale of the PRP paradigm is that processing of Task 1 causes a temporal delay in processing of Task 2 due to this serial central processing bottleneck. The duration of this delay depends on the task overlap between Task 1 and Task 2 (operationalized by the Stimulus Onset Asynchrony or SOA). If task overlap is large (i.e., small SOA), then the delay for Task 2 is assumed to be large, creating a gap in Task 2 processing (sometimes referred to as “cognitive slack time”). The PRP paradigm is often used to study temporal loci of certain effects (e.g., Dell'Acqua et al., 2007; Dent, Johnston, & Humphreys, 2008; Fagot & Pashler, 1992). In our study, we asked

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Fig. 1 – The Psychological Refractory Period paradigm. Task 1 processing (top bar) delays the central processing (in red) of Task 2 if the stimulus onset asynchrony (SOA) is short (middle bar). The delay period or “cognitive slack” time (gold) allows for resolving any interference effects due to perceptual processing (i.e., if the blue process takes more time, the onset of the red process will not change). When the SOA is long (lowest bar), interference due to perceptual processing cannot be resolved as no cognitive slack is available.

participants to indicate with a button press whether the pitch of an auditory stimulus was high, medium, or low (Task 1). After a certain duration, a picture was shown superimposed with a word, and participants were asked to name the picture (Task 2). The word could either name the picture (congruent condition, e.g., a picture of an elephant and the word “elephant”), or be unrelated to the picture (unrelated condition, elephant and “book”), or be a semantic category member (incongruent condition, elephant and “giraffe”). Any differences between these last two conditions are assumed to be the consequence of semantic interference. Importantly, interference effects that result from the initial encoding of the stimulus (“early” interference effects, blue in Fig. 1) may be resolved during the cognitive slack time if Task 2 follows Task 1 at short SOA, resulting in smaller response time differences between conditions, or no difference at all. On the other hand, late – post-cognitive slack – interference effects (red in Fig. 1) remain observable as response time differences between conditions.

Applying the PRP paradigm, we found that responses in the incongruent condition were slower than in the unrelated (and congruent) condition, *except* when Task 1 and Task 2 temporally overlap causing cognitive slack time, *and* the previous trial was a congruent trial (i.e., a hypothesized decrease in cognitive control). In accordance with the PRP logic, we termed this effect a shift of the locus of interference: Most conditions supported a late locus of interference (as SOA did not influence interference effects), but following the relaxation of cognitive control this appeared to shift to an early locus.

Shitova et al. found that the locus of the interference effect was at a lexical stage approximately 400 msec post stimulus onset (the “word-planning” stage). Crucially, the locus was *independent* of whether the previous trial was congruent or incongruent. This result appears in disagreement with our observation that the locus of the interference effect is a function of the previous trial's type. This discrepancy between their result and ours can be explained in multiple ways, with Shitova et al. focussing on two. Their first argument pertains to the question whether our experiment actually reveals a Gratton effect. They reanalyzed our data, focusing only on

data from the largest SOA-condition, and found no significant interaction between congruency condition and the previous trial. Since the overlap between Task 1 and Task 2 was minimal in those conditions, this seems to be the condition where a Gratton effect (i.e., such an interaction) should be observed. However, our PRP experiment precludes such a conclusion. Taking into account that 39% of all Task 1 responses are slower than the longest SOA (800 msec), temporal overlap between Task 1 and Task 2 should be present even for the longest SOA. Even if we assume that peripheral processing (e.g., a response stage) accounts for a sizable part of these response times, overlap between tasks is not unlikely for a large proportion of trials. The response times for Task 1 actually imply that for a truly non-overlapping condition the SOA should have been over 1.5s, as 95% of all responses to Task 1 are faster than 1524 msec. Thus, if the data do not contain (a reasonable proportion of) non-overlapping trials, the hypothesis that analyzing only large-SOA trials *must* show clear Gratton effects seems too strong. Instead, the analysis of our data should focus on whether the interference effect differs as a function of SOA in interaction with the previous trial type. This can be done by including SOA as a factor, which indeed reveals a significant three-way interaction.¹ The mean

¹ In our original analysis we included all three congruency levels. A reviewer pointed out that in order to find support for a dependence of the semantic interference effect on SOA and previous trial, the analysis should only include the Incongruent and Unrelated (current) trials, and only the Incongruent and Congruent previous trials. Unfortunately, the design of our experiment was not optimized for this analysis, and finding statistically significant effects will therefore be difficult. Nevertheless, we fit two linear-mixed effects models to the data, in which we predicted $\log(\text{RT})$ as a function of SOA, condition (Incongruent vs Unrelated) and previous-trial (Incongruent vs Congruent). A likelihood ratio test comparing these models shows a marginal effect ($\chi^2(4) = 9.4, p = .051$), hinting at a three-way interaction. Although we lose roughly one third of the trials by excluding congruent trials and trials that follow an unrelated trial, these analyses still weakly support our original interpretation of the data.

RT differences in the longest SOA condition are in the hypothesized direction, which therefore does support the interpretation that when participants would name the picture without any temporal overlap between Task 1 and Task 2, a significant Gratton effect should be revealed.

If the three-way interaction that we originally reported would have been a strong effect, it should have appeared as a two-way interaction in the longest SOA condition regardless. Thus, it may be possible that our results should be attributed to a type I error, which would be one way to reconcile the Shitova et al. (2017) with Van Maanen and Van Rijn (2010). Previous work on the relationship between semantic interference and SOA in PRP tasks remains ambiguous, with some researchers reporting a change in the observed interference effect with SOA (Ayora et al., 2011; Dell'Acqua et al., 2007; Kleinman, 2013; Van Maanen et al., 2012), and others reporting that the observed interference effect is not influenced by SOA (Piai, Roelofs, & Roete, 2015, 2014; Schnur & Martin, 2012). In a series of experiments, Piai, Roelofs, and Schriefers (2014; 2015) tried to find changes in observed interference effects across SOAs, but found no difference. By extension, they did not report a change in the Gratton effect across SOAs. Thus, a scenario in which our earlier result is attributable to a type I error is not completely unlikely. However, in what follows, we will argue that the theory that we developed to explain interference in the context of language production (RACE/A, Van Maanen & Van Rijn, 2010; Van Maanen, Van Rijn, & Borst, 2009; Van Maanen et al., 2012) in principle accounts for both findings.

The second line of argumentation against our findings put forward by Shitova et al. seems to reflect an important misconception of RACE/A. Shitova et al. argue that in our data the observed temporal locus of the Gratton effect differs in an all-or-none fashion because of the PRP paradigm. We agree with this argument to the extent that it applies to the *observed temporal locus*. This does not entail however that the interference shifts to another processing stage in an all-or-none fashion. Instead, we hypothesize that the observed interference effect reflects a difference in the efficiency of the retrieval of relevant information, which might occur during every processing stage of the task. An important aspect of our theory is that the retrieval of relevant information at a later stage (such as the word planning stage) depends on the retrieval process at an earlier stage (e.g., perceptual processing or concept retrieval). This entails that differences in the efficiency of concept retrievals, which could be driven by the (in) congruency of the stimulus, also drive differences in the efficiency of lexical retrievals on a later stage. Because the PRP paradigm assumes a delay in processing between stages, the magnitudes of the interference effects differ per SOA condition, and therefore we observed a shift in the interference effect.

Here, we present various simulations with the model we presented in Van Maanen and Van Rijn (2010) that illustrate this point. Each panel of Fig. 2 shows the activation dynamics of two competing responses (solid and dashed lines), for two consecutive stages (an early perceptual stage in blue, and a late stage in red, which could reflect central processing) of Task 2. These competing responses might reflect the retrieval of conceptual information pertaining to the picture and the

word, respectively, in the first stage, and the retrieval of associated word-plans in the second stage. Task 1 is not depicted in Fig. 2, but the onset of Task 2 relative to Task 1 determines the cognitive slack duration. When the Task 2 stimulus is presented (a picture-word combination), accumulation of activation of the relevant conceptual representation begins (at time point 0) until a concept is retrieved (see Van Maanen & Van Rijn, 2010; Van Maanen et al., 2012 for detail of the computations). The moment in time when this occurs is depicted by a vertical dashed line in Fig. 2. After retrieval, the activations of the response options are assumed to decay back to their baseline values. Due to the PRP-induced overlap with Task 1, Task 2 can only continue after a delay period (cognitive slack time, in gold). Crucially, the retrieval latency in this later, response stage is heavily dependent on the remaining activation dynamics from the early stage, as these activation levels influence the speed of activation accumulation to produce the response. Thus, interference at the early stage will be expressed both at an early and at a later stage of processing. The magnitude of such 'carry-over' of interference depends on the activation level that was attained before the first retrieval terminated the perceptual stage, as well as on the duration of the cognitive slack time during which these activation levels decay. Such a cascade of activations (McClelland, 1979) from one stage to the next may thus result in interference at all processing stages, but in different magnitudes.

The nine panels of Fig. 2 represent different combinations of degree of interference and partial task overlap, illustrating that these components together predict shifts in the observed locus of interference. From top to bottom, the panels represent increasing task overlap (i.e., decreasing SOA), causing increasing cognitive slack between the offset of the first processing stage and the onset of the second processing stage of Task 2. Limited task overlap, caused by longer SOAs, result in only a short decay period. This results in relatively high spreading activation from the earlier activated conceptual representations, leading to a short duration of the second stage. This is indicated by the time difference between stage onset (where the red lines initiate) and retrieval.

From left to right, the panels represent differences in the amount of interference in the first processing stage, visible in the lengthening of the blue bar (note the inverse logarithmic scale). In the leftmost panels the interference is limited, as might be the case for an unrelated picture-word stimulus; in the middle panels, the interference is larger, as might be the case for an incongruent picture-word stimulus following another incongruent trial; in the right panels, the interference is largest, as might be the case for an incongruent trial following a congruent trial.

Fig. 2 illustrates that the model we proposed (Van Maanen & Van Rijn, 2010) predicts that the PRP paradigm – consistent with Shitova et al.'s interpretation – influences the cognitive processing, because the delay between consecutive stages affects the amount of interference in the second, post-cognitive slack stage (depicted in red). This is reflected by the different activation during stage 2 (red lines) from top panels to bottom panels (note that the x-axis is on an inversed log scale to focus on the critical time period). However, this does not entail an abrupt change in the locus of interference,

Fig. 2 – Activation dynamics of the RACE/A model of semantic interference. Blue lines represent activation in stage 1 (pre-slack); red lines represent activation in stage 2 (post-slack). Solid lines indicate target activation; Dashed lines indicate distractor activation. The colored bars indicate the duration of each processing stage. Y-axis is on a logarithmic scale; X-axis is on an inversed logarithmic scale. Time is locked to the predicted response time. See text for details about the different panels.

but rather a gradual change in the duration of processing stages (Fig. 3).

Importantly, the computational model provides a tentative explanation for the results of Shitova et al. (2017). Their ERP time courses suggest a relatively late locus of the Gratton effect, hypothesized to reflect more or less interference at the word-planning stage. At first sight, this might appear to contrast our model simulations in which the largest SOA (i.e., minimal slack time) is associated with interference effects mainly observable at an early locus (Top row of Fig. 2). However, the stage durations are influenced by a set of parameters reflecting aspects of the task, stimuli, or participants which may differ from one experiment to another. It is conceivable that behavior in the single-task experiment by Shitova et al. was governed by a different set of parameters, changing the dynamics of cognitive processing. If we assume that the spreading activation between conceptual representations and word-plans is stronger, and we assume stronger decay of activation, RACE/A predicts the RT profile that Shitova et al. found (Fig. 4). These study differences could emerge through the use of items that differ in their associative strength. For

example, the semantic association between a picture of an elephant and the word “giraffe” might be higher than the semantic association between a picture of a moped and the word “tractor”, even though both items constitute pairs of category members (animals and vehicles, respectively). In addition, population differences, for example in prior experience with certain items, could also influence the results. The activation levels of items depend on prior experience and usage, potentially resulting in stage duration differences and ultimately behavioral differences.²

It should be stressed that our study and model are not intended to show that semantic interference is confined to a particular processing stage, but rather that details of an

² A similar line of reasoning may explain the lack of a Gratton effect in the reanalysis of the dual-task experiment by Piai et al. (2014) that Shitova et al. report. An important additional comment to make about this data is that Piai et al. do not find a two-way interaction between interference condition and SOA, contrary to Van Maanen et al. (2012). This may potentially be an indication that the differences in experimental setting make these data sets less comparable.

Fig. 3 – Predicted difference in stage durations and response times (RT) for medium and large interference relative to limited interference. Left: Medium interference stage durations minus limited interference stage durations; Middle: Large interference stage durations minus limited interference stage durations. Colors indicate processing stages; Right: Response time differences. Colors indicate slack time. Note the reversal of the predicted interference effect for large task overlap, which is sometimes observed in data as well (e.g., Dell’Acqua et al., 2007, although to our knowledge never examined in detail).

Fig. 4 – Model prediction for a late observed locus of interference. Contrary to the original model, this prediction is based on a model that does not assume slack time between processing Stage 1 and 2 as would be the case in Shitova’s single-task paradigm. Additionally, the model parameters are slightly modified, most notably the connection strength between the competing semantic representations, and the level of decay of activation.

experimental setting influence the entire processing stream, and as such the measurable behavior.

In this commentary, we aimed to provide a more thorough explanation of the theory that we put forward regarding semantic interference in PRP experiments. Specifically, we argue that the inference that the functional locus of semantic interference has shifted in an all-or-none fashion due to the nature of the previous trial is not necessarily warranted. Rather, we view interference as a more fluid process, that may

or may not appear in behavioral measures (response times) depending on many properties of the task, including properties of the stimulus (Van Maanen et al., 2009), properties of the trial sequence (Van Maanen et al., 2012; Van Maanen & Van Rijn, 2010), and other properties of the experimental design, such as the PRP manipulation. In their paper, Shitova et al. corroborated these considerations by providing evidence for an observed locus of the interference effect at the word-planning stage.

While some researchers have observed a change in the observed interference effect with SOA (Ayora et al., 2011; Dell’Acqua et al., 2007; Kleinman, 2013; Van Maanen et al., 2012), this is not a common finding (Piai et al., 2015, 2014; Schnur & Martin, 2012). In our opinion, these divergent results suggest that the retrieval dynamics during lexical processing are complex, and illustrate the need for precise computational models of such phenomena. Given the complexity of the language system, a formalization of assumptions of the theory is often required to understand the predictions of the theory (also argued by a.o. Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992; Van Rijn, Borst, Taatgen, & Van Maanen, 2016). However, such complex models are often difficult to validate, given that the high complexity of the models comes with increased flexibility (Roberts & Pashler, 2000), and given that estimating parameters on the basis of data is increasingly problematic for such models (Miletic, Turner, Forstmann, & Van Maanen, 2017; Turner, Sederberg, & McClelland, 2016). For this reason, the simulations reported in this commentary should be considered as qualitative predictions (Turner, Forstmann, Love, Palmeri, & Van Maanen, 2017) of our theory of semantic interference, that require corroboration from sophisticated cognitive models (Anders, Ries, Van Maanen, & Alario, 2015), advanced analyses techniques (Borst & Anderson, 2015), and elegant experimentation (Shitova, Roelofs, Schriefers, Bastiaansen, & Schoffelen, 2016; 2017). Shitova and colleagues have made a very valuable contribution in this respect.

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