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Distributional analyses in the picture-word interference paradigm: Exploring the semantic interference and the distractor frequency effects.

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Running head: Distributional Analyses in the PWI

Distributional analyses in the picture-word interference paradigm: Exploring the semantic interference and the distractor frequency effects.

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Abstract

The present study explores the distributional features of two important effects within the picture-word interference paradigm: the semantic interference and the distractor frequency effects. These two effects display different and specific distributional profiles. Semantic interference appears greatly reduced in faster response times, while it reaches its full magnitude only in slower responses. This can be interpreted as a sign of fluctuant attentional efficiency in resolving response conflict. In contrast, the distractor frequency effect is mediated mainly by a distributional shift, with low frequency distractors uniformly shifting reaction times distribution towards a slower range of latencies. This finding fits with the idea that distractor frequency exerts its effect by modulating the point in time in which operations required to discard the distractor can start. Taken together, these results are congruent with current theoretical accounts of both the semantic interference and distractor frequency effects. Critically, distributional analyses highlight and further describe the different cognitive dynamics underlying these two effects, suggesting that this analytical tool is able to offer important insights about lexical access during speech production.

Keywords: picture-word interference; distributional analyses; semantic interference; distractor frequency

Introduction

The picture-word interference (PWI) paradigm has been one of the leading tools to investigate lexical access during word production. In a classic version of this task (e.g., Glaser & Düngelhoff, 1984; Lupker, 1979; Rosinsky, 1977) a distractor word is presented superimposed on a target picture. Participants are instructed to name the picture aloud, while ignoring the word. In this context, naming latencies are influenced by the relationship between the picture's name and the distractor word, as well as by specific properties of the distractors themselves. In fact, two distractor effects that have proven to be critical for models of word production are the semantic interference and the distractor frequency effects. The semantic interference effect refers to the fact that when the distractor word is a semantic-category coordinate of the picture, the latter is named more slowly compared to when the distractor is not a semantic-category coordinate (see MacLeod, 1991). On the other hand, the distractor frequency effect attributes the fact that pictures are named faster when presented with high frequency word distractors, compared to low frequency ones (Miozzo & Caramazza, 2003). Notwithstanding the lack of consensus on the theoretical interpretation of the two phenomena, across different proposals some similarities are found in the description of the cognitive dynamics underlying the two effects. The present research aims to explore and test these converging intuitions via distributional analyses.

Following the commonly held idea that activation at the conceptual levels spreads from the target onto similar concepts and from these concepts to associated lexical representations (e.g., Dell, 1986; Levelt, Roelofs, & Meyer, 1999; Caramazza, 1997), for competitive models of lexical selection (Roelofs, 1992; 2003) a semantic-category coordinate distractor would receive not only bottom-up activation from the written word, but also top-down activation from the semantically related picture. As a consequence, the lexical activation for this sort of distractors would be higher compared to those that do not belong to the same semantic category as the target picture. Since lexical selection is shaped as a competitive process, longer response times are predicted when the activation of the distractor is higher, readily explaining the semantic interference effect. Different hypotheses locate the phenomenon of semantic interference further down in the processing stream that leads to word production. For instance, the response exclusion hypothesis (Finkbeiner & Caramazza, 2006; Mahon, Costa, Peterson, Vargas & Caramazza, 2007) assumes that the distractor words have a privileged relationship with the articulators. As such, before picture naming can take place, distractor words have to be discarded from a post lexical output buffer. The time needed to remove the distractor from the buffer depends, among other things, on whether or not the distractor word shares response relevant criteria with the target. Semantic category of the target is used as one of these response relevant criteria. As such, when there is an overlap between the distractor and the target with respect to this dimension, discarding the distractor becomes more difficult, thus yielding longer latencies (e.g., Lupker, 1979; for a detailed discussion see Mahon et al., 2007; Mahon, Garcea, & Navarrete, 2012).

Although the two frameworks posit different loci for the semantic interference effect, both accounts seem to suggest that central attention play a crucial role in this phenomenon. Lexical selection by competition describes picture naming within the PWI paradigm as a process of response selection, in which the system has to overcome response conflict (e.g., Roelofs, 2003). On the other hand, Dhooge and Hartsuiker (2012) have recently proposed that hypothetical mechanisms postulated in the response exclusion hypothesis can be better described as speech-monitoring processes operating once lexical access has occurred. Although different theories of speech monitoring posit different degrees of involvement for central attention (e.g., Postma, 2000), available evidence suggests that monitoring does rely on central executive attention. For example, monitoring requires time to unfold properly, and is disrupted under time pressure (Dhooge & Hartsuiker, 2012) or in conditions of divided attention (e.g., Oomen & Postma, 2002).

Recent lively debates (e.g., Dhooge & Hartsuiker, 2010; 2011; 2013; Roelofs, Piai, & Schriefers, 2011) also testify to the large disagreement on the origin of the distractor frequency effect. According to the competitive model of lexical selection WEAVER++, the distractor frequency effect is a by-product of a selective attention mechanism that prioritizes processing for the picture by reactively blocking the word representation (Roelofs, 2005; Roelofs et al., 2011). The speed of blocking depends on the speed of word form encoding for the distractor word; the earlier this information is available, the earlier it can be blocked. Thus, high frequency words can be blocked faster compared to low frequency ones. According to the response exclusion hypothesis (Mahon et al., 2007), the distractor frequency effect is explained on the assumption that high frequency distractors gain access to the buffer earlier than low frequency distractors. In this scenario, high frequency distractors would be available for discarding operation earlier than low frequency words.

Despite some clear differences, again these two accounts show some commonalities in their explanations of the distractor frequency effect (see also Roelofs et al., 2011). Both theories argue that the system needs to discard the distractor and that this operation is a function of the processing speed of the distractor itself. It is also important to note that, in both accounts, frequency does not directly influence those processes underlying the blocking/removal of the distractors. In other words, frequency does not alter the processes needed to discard the distractor, instead it determines the point in time at which these processes can start to operate (see Ayora, et al., 2011; for further discussion, Finocchiaro & Navarrete, 2013).

In summary, while the semantic interference effect is shaped by attentional control, the distractor frequency effect would be a mere by-product of the distractors' speed of processing. The aim of the present work is to highlight these specific and different cognitive dynamics underlying the two phenomena. We aim to do that by exploiting distributional analyses. In fact, although this tool has been previously used in the word production literature (e.g., Piai, Roelofs, & Schriefers, 2011; 2012; Roelofs, 2008a; Shao, Roelofs, & Meyer, 2012) and holds a solid tradition in related fields (such as visual word recognition and the Stroop paradigm), it has not yet been used to systematically compare the semantic interference and the distractor frequency effects, with the specific aim to further characterize the underlying cognitive processes.

Distributional analyses

Reaction times (RTs) are asymmetrically distributed around the mean, as their distribution is virtually always positively skewed (Balota & Yap, 2011). In this scenario, the exclusive reliance on a measure of central tendency -such as the mean- may lead to a loss of information. However, there are two different viable ways to address this peculiarity of the RT distribution. One is to follow a parametric approach, and to fit the empirical RT distribution to a mathematical function. Although different mathematical functions might serve this scope, researchers agree on the notion that RTs are adequately described by ex-Gaussian functions (Balota & Yap, 2011; Heathcote, Popiel, & Mewhort, 1991). These functions, which originate by the convolution of a Gaussian component and an exponential one, are described by three parameters: μ, σ and τ. While μ and σ reflect, respectively, the mean and the standard deviation of the Gaussian component, τ describes mean and standard deviation of the exponential one. Critically, μ and σ capture the normally distributed portion of the RT distribution, while τ describes the slower tail.

Differently, we can describe the RTs without specific parametric assumptions about the shape of their distribution. In this non-parametric approach, RTs for each participant in each condition are rank-ordered and divided into quantiles (e.g., Ratcliff, 1979). Quantile-means are then calculated and averaged across subjects. In this way, for instance, measures of different experimental conditions are provided as a function of quantiles (i.e., across the distribution). Also, it is possible to have a clear picture about how a specific effect unfolds across the distribution by simply considering the difference between the two experimental conditions of interest as a function of quantiles (e.g., Balota, Yap, Cortese, & Watson, 2008).[1]

Bearing these premises in mind, different scenarios may underlie an effect detected with the standard analyses. In a first one, the difference between the two experimental conditions simply reflects the shift of the RT distribution of one condition with respect to the other. In these instances, the effect is constant across different quantiles, and this is captured by change in the μ parameter. In a second scenario, the effect is located mainly in the slower quantiles of the RT distribution and is reflected as a change limited to the τ parameter. Finally, an effect may concurrently reflect the two patterns outlined above, thus producing variations both in the μ and the τ parameters. These different (ideal) scenarios are represented in Figure 1 (respectively in the first, second, and third row). As can be seen, the two approaches (i.e., parametric and non-parametric) usually provide a converging picture of the examined phenomenon (Balota et al., 2008).

(Figure 1 about here)

Crucially for the purposes of this study, different distributional patterns can be used to explore different theoretical accounts underlying the phenomena. For example, the finding that semantic priming in visual word recognition assumes the shape of a distributional shift (Balota, et al., 2008) fits nicely with the idea that the effect is the result of a head-start mechanism in which the target is pre-activated by the prime (e.g., Neely, 1991). On the other hand, the finding that the transposed-letter neighbourhood effect (i.e., words such as *angel* that has a transposed letter neighbour, *angle*, are more difficult to read than words with no such neighbours) affects selectively the slowest RTs suggests that the phenomenon may not reflect increased competition amongst similar lexical representation, but rather stems from the need to inhibit an output that has been incorrectly activated in a subset of trials (Johnson, Staub, & Fleri, 2012).

Outline of the present study

Distributional analyses have been used to highlight and describe attentional dynamics in interference effects. De Jong, Berendsen, and Cools (1999) showed that interference in a manual Stroop task was almost absent in fastest responses, and appeared in full magnitude only on slower trials (for further empirical evidence see Hommel, 1997; Pratte, Rouder, Morey, & Feng, 2010). According to the authors, the pattern reflects fluctuations of the efficiency of executive control, rather than structural limitations of inhibitory capabilities. In other words, the fact that in some instances (i.e., fastest trials) the system fully or strongly suppresses interference, while in others (i.e., slowest trials) it does not, seems more congruent with the idea that interference reflects inability to consistently deploy inhibitory attentional capabilities. By contrast, if interference is an unavoidable phenomenon stemming from the system's structural limitation, the effect should have been observed all across the distribution (for further application of a similar logic in other tasks, see Roelofs, 2008a).

The theoretical accounts of the semantic interference effect reviewed above (i.e., the lexical selection by competition and the response exclusion accounts) seem to converge on the idea that attention plays an important role in this phenomenon. As such, it is interesting to apply the logic outlined by De Jong and colleagues (see also Roelofs, 2008a) to the semantic interference effect in the PWI paradigm in order to investigate whether its distributional shape is more congruent with the idea that the phenomenon stems from fluctuant attentional efficiency or from a structural limitation of the system. Again, in the former case we would expect to see no (or dramatically reduced) semantic interference in fastest responses, and full-blown interference just in the slower tail (i.e., the effect would mainly affect the τ parameter). Differently, if semantic interference reflects a consistent and unavoidable limitation in inhibitory capability, a consistent effect should be found all across the distribution (i.e., the effect should be mainly mediated by μ). Some data are already available in the literature, as Piai and colleagues (2011; 2012) offered pioneering investigations of the distributional features of the semantic interference effect. However, the results are somewhat mixed. In one study (Piai et al., 2011) the semantic interference effect seems to be mediated mainly by a distributional shift, while in the other study (Piai et al., 2012) the effect is located in the exponential tail. Thus, further investigation seems warranted.

With respect to the distractor frequency effect, both the accounts reviewed above agree on the notion that frequency does not alter the processes of distractor's blocking/removal per se, as it just influences the point in time in which these operations can actually start. This suggests that the effect should involve mainly a distributional shift. Compared to high frequency distractors, low frequency distractors are assumed to be available later for blocking/exclusion operations and, as such, RTs corresponding to pictures presented with low frequency distractors may be uniformly shifted towards slower ranges of latencies. Recently, Geng, Schnur, and Janssen (2014) have reported that the distractor frequency effect is absent or negligible in fastest and slowest quantiles, while it is present just in the middle ones. Clearly, this contrasts with the predictions derived from the two theoretical accounts of the distractor frequency effects we have described. It is important to note that Geng and colleagues conducted their quantile analyses on data from different experiments, jointly considering 2 PWI experiments and 3 Stroop-like experiments. Therefore, it is not clear to what extent the reported pattern reflects (a) the distributional shape of the distractor frequency effect in the PWI paradigm, (b) the distributional shape of the distractor frequency effect in the Stroop-like paradigm, or (c) a convolution of two (different) distributional profiles.

In summary, we report three PWI experiments exploring the distributional features of the semantic interference and of the distractor frequency effect. In Experiment 1, where we explored the semantic interference effect, pictures were presented either with semantic-category coordinate distractors or with unrelated distractors. In Experiment 2, where we addressed the distractor frequency effect, the same set of pictures used in Experiment 1 was presented with high frequency and low frequency distractors. In addition to those conditions, in experiments 1 and 2 we included an identity condition (in which the distractor word was the name of the picture itself) and a neutral condition (a string of 6 Xs). Note that the identity and the neutral conditions are very similar to the congruent (e.g., the word "RED" in red font) and the neutral (e.g., the stimulus "XXXXX" in red ink) conditions implemented in the Stroop task. The comparison between these two conditions in the Stroop paradigm has consistently shown a peculiar distributional pattern, which has been interpreted as a sign of the fact that while μ reflects response conflict, τ reflects task conflict (Roelofs, 2012; Steinhouser & Hübner, 2009; for neuroimaging evidence, see also Aarts, Roelofs, & van Turennout, 2009). This interpretation is clearly different from what we are proposing here. As such, it is useful to investigate whether the peculiar pattern that fostered this interpretation is replicated in the PWI paradigm as well. Finally, in Experiment 3 we investigated the semantic interference and the distractor frequency effects within the same group of participants, to ensure that any difference in terms of distributional profiles was truly reflecting cognitive processes operating at the trial level, and not just between-participants differences in performing the task.

Experiment 1

Method

Participants. Twenty-four undergraduate students from the University of Padova participated to the experiment on the basis of voluntary agreement. All of them were native Italian speakers and reported normal or corrected-to-normal vision. Before beginning the experiment, participants read and signed a written consent form.

Materials. Sixty black and white drawings were selected from different databases (Alario, & Ferrand, 1999; Dell'Acqua, Lotto, & Job, 2000; Bonin, Peerman, Malardier, Meot, & Chalard, 2003). For the semantically related condition, a semantic-category coordinate distractor word was selected for each picture. To create picture-word pairs for the semantically unrelated condition, words were randomly re-assigned to pictures. Picture-word pairs used in the semantically related an unrelated conditions are listed in the Supplemental Material. In both conditions, pictures and their corresponding distractors did not share the same onset phoneme. Properties of word-distractors are listed in Table 1. For the identity condition, pictures were presented with their name, while in the neutral condition a string of 6 Xs was superimposed on the pictures.

(Table 1 about here)

Using this set of stimuli, two groups of 12 lists per group were created. For each list of the first group, each picture appeared once in each of the 4 experimental conditions (semantically related distractor, semantically unrelated distractor, identity distractor, and neutral distractor) for a total of 240 trials. Presentation of the stimuli within each list was pseudo-randomized following three criteria. Specifically, (a) presentations of a picture were separated by at least 30 trials during which different pictures were presented, (b) the same experimental condition could not be repeated for more than 3 consecutive trials, and (c) two pictures of the same semantic category could not be presented in consecutive trials. Using this first group of 12 lists, the second group of lists was created by reversing the order of presentation of the original lists. Each participant, during the experiment, was presented with a list from the first and a list from the second group (for a total of 480 trials) and care was taken so that the same participant did not see a list and its reversal. The order of presentation of the lists within participants was counterbalanced so that, across participants, the same list appeared an equal number of times as the first and as the second list.

Finally, a further set of 8 pictures was selected to be used in the practice session or as filler trials in the experiment (see Procedure). Six of these pictures were paired with semantically unrelated words, none of which was used for experimental trials. The other two pictures were paired with the neutral distractor.

Apparatus and Procedure. The experiment took place in a dimly lit room. Participants were seated 50 cm from the computer screen on which stimuli were displayed, wearing a headset microphone. Stimulus presentation and response recording were controlled by DMDX software (Forster & Forster, 2003). Naming latencies and accuracy were determined off-line using the CheckVocal software (Protopapas, 2007).

The experiment began with a familiarization phase, divided in 2 stages. In the first stage, participants were presented with all the pictures along with their corresponding names written below and were instructed to name them aloud. In the second stage, the pictures were presented again but without the corresponding name. Participants were instructed to name them aloud, using the same names of the previous stage and, after each response, the name of the picture appeared below the picture itself, providing feedback on the accuracy.

Once the familiarization phase was over, participants were presented with the instruction for the PWI experiment. They were instructed to name the picture aloud, while ignoring the superimposed distractor. Accuracy and speed were equally emphasized. After a brief practice-phase (8 trials), instructions were presented again and then the experiment started. The experimental phase was divided into 8 blocks of 60 trials. At the end of each block, participants were prompted to take a self-terminated break. The 2 trials at the beginning of each block were filler trials, randomly selected from the pool of practice trials.

Each trial started with a fixation cross (+), lasting 750 ms. After a blank screen lasting 250 ms, the stimulus (a picture with the superimposed distractor) was displayed until participant's response. If no response was detected, the next trial began 2000 ms after the stimulus onset. Pictures were 300 x 300 pixels large and were displayed centrally on the screen (with a resolution of 1024 x 768). Distractor words were presented centrally as well, superimposed on pictures and in capital letters (Times New Roman font, 13 points).

Results

Trials in which errors (2.57%) or voice-key failures (0.3%)[2] occurred were removed from the RTs analyses. The remaining RTs were submitted to a recursive trimming procedure, in which the criterion for outliers' removal was determined by the sample size of each experimental cell (see Van Selst & Jolicoeur, 1994). This procedure resulted in the removal of a further 2.5% of the data. We report analyses for the semantic interference effect (semantically related vs. unrelated distractors) and for the identity effect (identity vs. neutral distractors). Distractor type was treated both as a within-participants (F_1/t_1) and as a within-items (F_2/t_2) variable. In all analyses reported in this article, Greenhouse-Geisser corrections were applied when the sphericity assumption was violated.

Semantic Interference effect.

Accuracy. The difference in accuracy between pictures presented with semantically related and unrelated distractors approached significance only in the by-participant analysis, t_1 (23) = 1.81, p = .08, d = .32, t_2 (59) = 1.3, p = .19, d = .15. Mean accuracy as a function of distractor type is reported in Table 2.

Mean RTs. The experiment replicated the classic semantic interference effect on mean latencies, t_1 (23) = 5.52, p < .001, d = 1.17, t_2 (59) = 4.15, p < .001, d = .54, with semantically related distractors yielding slower RTs. Mean RTs as a function of condition are listed in Table 2.

Ex-Gaussian analyses. Best-fitting ex-Gaussian parameters (μ, σ, τ) were estimated for each participant and each condition via maximum likelihood estimation using the QMPE v2.18 software (Cousineau, Brown, & Heathcote, 2004; Heathcote, Brown, & Mewhort, 2002). The procedure implemented in this software involves the division of the empirical RTs into quantiles. Following Heathcote et al. (2002; see also Rouder, Lu, Speckman, Sun, & Jiang, 2005; White & Staub, 2012), in the fitting procedure RTs were divided into the maximum number of quantiles, so that each single data point was placed in a separate quantile. Separate comparisons were conducted for each of the estimated parameters.

The difference between estimates of the μ parameter for the semantically related and the semantically unrelated conditions failed to fully reach the conventional level of statistical significance, t (23) = 1.87, p = .07, d = .41, suggesting that the bulk of the effect might not resemble a distributional shift. Also, the effect was not significant with respect to σ, t (23) = 1.08, p = .29, d = .23. On the other hand, the effect was significant for the τ parameter, t (23) = 3.61, p < .01, d = .73, suggesting that semantic interference is mainly mediated the exponential component of the RT distribution. Mean estimated parameters are reported in Table 2.

Quantile analyses. RTs for each participant in each condition (i.e., each of the 4 distractor types) were divided in 10 quantiles (deciles). Mean RTs as a function of condition in each quantile (collapsed across participants) are plotted in Figure 2. Following Roelofs (2008a; 2008b) we also computed by-items quantiles, partitioning the RTs distribution for each item in each condition in 10 deciles. This enabled us to run by-items quantile analyses, and thus to inspect that the reported results are not mere by-products of specific subsets of items.

(Figure 2 about here)

As can be seen in Figure 2, the difference across the semantically related distractor condition and the semantically unrelated distractor condition appears to be fully displayed in slower deciles, while it is greatly reduced in the fastest responses. To formally test this, we ran an analysis of variance (ANOVA) considering deciles and distractor type (semantically related vs. semantically unrelated) as within-participant and within-items factors. The interaction between the two factors was significant in the analysis by participants, F_1 (2, 40) = 5.14, $p < .05$, $MSE = 4287.81$, $\eta^2_p = .18$, and approached conventional levels of significance in the analysis by items, F_2 (1, 99) = 2.72, $p = .08$, $MSE = 2345.82$, $\eta^2_p = .04$, confirming the variation of the effect across the distribution. Interestingly, when considering just the first decile, the semantic interference effect detected in the analysis by participants consists in just a 10 ms difference (95% CI [0, 20]). The effect in the first decile is only approaching the conventional levels of significance in the analysis by participants, t (23) = 1.93, p = .07, d = .38, while it is not significant in the analysis by items, $t_2 < 1$. The by-participants semantic interference effect as a function of deciles is displayed in Figure 3. Note that, compared to empirical ones, quantiles based on the estimated ex-Gaussian parameters tend to overestimate the effect. However, given the converging interaction found in the quantile analyses, we are confident about the fact that the effect is significantly enhanced in slower trials.

Identity effect.

Accuracy. The identity effect was significant, t_1 (23) = 2.72, p < .05, d = .56, t_2 (59) = 3.21, p < .01, d = .4, with the Identity distractor condition yielding higher accuracy (Table 2).

Mean RTs. The identity effect is significant, t_1 (23) = 6.15, p < .001, d = 1.25, t_2 (59) = 11.32, p < .001, d = 1.43, as participants were faster in the identity distractor condition, compared to the neutral one (Table 2).

Ex-Gaussian analyses. The identity effect was significant both with respect to the parameters μ, t (23) = 3.05, p < .01, d = .61, and τ, t (23) = 3.09, p < .01, d = .64, while it was not significant for σ, t (23) = 1.28, p = .21, d = .29. Mean estimated parameters are listed in Table 2.

(Table 2 about here)

Quantile analyses. The interaction between the identity effect and deciles was significant in the analyses by participants, F_1 (2, 36) = 9.4, p < .01, MSE = 2061.25, η^2_p = .29, as a larger facilitatory effect is found in slower RTs (Figure 3). However, the interaction failed to reach significance in the analysis by items, F_2 (2, 123) = 1.38, p = .25, MSE = 2957.42, η^2_p = .02.

(Figure 3 about here)

Discussion

Experiment 1 replicated the classic semantic interference effect, with slower mean RTs when pictures are presented with a semantic-category coordinate distractor, compared to the situation in which the distractor word is not a semantic-category coordinate word. Interestingly, this phenomenon mainly affects the slower tail of the RT distribution and it is remarkably reduced in the fastest responses. By applying here the same logic that has been applied to other interference effects (e.g., De Jong et al., 1999; Roelofs, 2008a), this distributional shape can be interpreted as a marker of the variability in the efficiency of attentional functions required to resolve interference itself. Despite the substantial reduction of the effect in faster RTs, however, the present results cannot rule out the presence of a residual semantic interference effect even in fastest RTs. So, although participants may be able to strongly control and reduce the interference produced by semantic category coordinate distractors, semantic interference may not be completely avoided.

A second intriguing finding is the distributional shape of the identity effect. Clearly, this effect has a facilitatory nature: Pictures presented with an identity distractor are named faster compared to when they appear in the neutral condition. This is not surprising as in the identity condition words are likely to prime the pictures' conceptual and lexical representations, and this sort of priming via pre-activation is known to produce a distributional shift (Balota et al., 2008). This facilitatory effect dramatically increases in the slower deciles, at least according to the ex-Gaussian and the by-participants quantile analyses. A similar shape for the semantic priming effect in visual word recognition has been interpreted as a sign of increased reliance on prime information for the slowest responses (Balota et al., 2008; Yap, Tse, & Balota, 2009; see also Scaltritti, Balota, & Peressotti, 2013; Thomas et al., 2012). It thus seems that, even in picture naming, participants rely more on the word distractor/prime during slower responses.

The pattern of the identity effect clearly contrasts with the one usually found in the Stroop task (e.g., Heathcote et al., 1991; Spieler, Balota, & Faust, 2000), where it has been consistently shown that the congruent condition, compared to the neutral one, produces facilitation only in the Gaussian component (i.e., the μ parameter) of the RT distribution, while yielding slower latencies in the exponential one (i.e., the τ parameter). Recently, it has been proposed that this distributional shape stems from the fact that while μ reflects response conflict, τ reflects task conflict (Aarts et al., 2009; Roelofs, 2012; Steinhouser & Hübner, 2009). This latter interpretation has been fostered by the fact that, while the congruent trials do not yield any response conflict, these may produce task conflict by activating the word-reading task, rather than the colour-naming task. Coherently, the congruent condition yields larger τ estimates compared to the neutral condition, where the string of Xs does not activate alternative tasks. This different interpretation of the ex-Gaussian parameters, however, does not seem to hold in the PWI paradigm: In our experiment, the identity condition always yielded much smaller τ estimates compared to the neutral one.

Experiment 2

Method

Participants. Twenty-four undergraduate students from the University of Padova participated in this second experiment, and they were included using the same criteria as in Experiment 1.

Materials. Pictures were the same as in Experiment 1. For each picture, we selected one high frequency and one low frequency word from the VARLESS database (Barca, Burani, & Arduino, 2002) to be used as distractors in the high frequency distractor and in the low frequency distractor conditions. Pictures and paired distractor words did not share onset phoneme (see Supplemental Material). High and low frequency words were comparable in terms of age of acquisition, imageability, concreteness, number of letters, number of phonemes, number of syllables, orthographic neighbourhood, and mean bigram frequency (see Table 1). The identity and neutral conditions were the same as in Experiment 1 and the construction of the experimental lists followed the same criteria and procedures illustrated for Experiment 1.

Apparatus and Procedure. The two experiments were run in parallel in two equally equipped labs: apart from the physical location, the apparatus was the same. The procedure was the same as in Experiment 1.

Results

Trials in which errors (1.26%) or voice-key failures (.29%) occurred were removed from all the RTs analyses. The recursive trimming procedure (Van Selst & Jolicoeur, 1994) removed a further 2.99% of the data. As for Experiment 1, we report separately the analysis for the distractor frequency effect (high frequency vs. low frequency) and for the identity effect (identity vs. neutral).

Distractor frequency effect.

Accuracy. There was no significant distractor frequency effect on mean proportion of correct responses (Table 3), t_1 (23) = 1.04, p = .31, d = .13, t_2 < 1.

Mean RTs. The experiment replicated the standard distractor frequency effect: responses were faster for trials with high frequency distractors, compared to those with low frequency ones, t_1 (23) = 7.21, p < .001, d = 1.48, t_2 (59) = 6.21, p < .001, d = .8. Mean RTs as a function of distractor type are listed in Table 3.

Ex-Gaussian analyses. The distractor frequency effect was significant just with respect to the μ parameter estimates, with smaller estimates for the high frequency distractor condition, compared to the low frequency one, t (23) = 5.73, p < .001, d = 1.15. The effect was not significant neither in σ, t < 1, nor in τ, t (23) = 1.41, p = .17, d = .3. Mean estimated parameters are listed in Table 3.

Quantile analyses. By-participants mean RTs for each condition as a function of deciles are plotted in Figure 4. The interaction between the distractor frequency effect and deciles did not reach the conventional level of statistical significance, F_1 (2, 41) = 2.87, p = .07, MSE = 1403.47, η^2_p = .11, F_2 (2, 96) = 1.54, p = .22, MSE = 6192.5, η^2_p = .02. As can be seen from visual inspection of Figure 4, the effect was constantly present since the fastest quantiles, and it only slightly increased in the last two deciles. The statistical analyses revealed that the effect was fully reliable even when limiting the analyses to the first decile, t_1 (23) = 4.83, p < .001, d = .96, t_2 (59) = 6.16, p < .001, d = .82, where, according to the analysis by participants, it measured 24 ms (95% CI [14, 34]). The by-participants distractor frequency effect as a function of quantiles is plotted in Figure 5.

(Figure 4 about here)

Identity effect.

Accuracy. The identity effect was significant, t_1 (23) = 4.38, p < .001, d = .85, t_2 (59) = 4.13, p < .001, d = .52, with higher accuracy in the identity compared to the neutral condition (Table 3).

Mean RTs. The identity effect was also significant in terms of mean RTs, t_1 (23) = 6.97, p < .001, d = 1.43, t_2 (59) = 13.83, p < .001, d = 1.76, with the identity condition yielding faster latencies (Table 3).

Ex-Gaussian analyses. As in the previous experiment, the identity effect significantly affected both μ, t (23) = 4.69, p < .001, d = .96, and τ, t (23) = 4.11, p < .001, d = .83, but not σ, t < 1. Mean estimated parameters are listed in Table 3.

(Table 3 about here)

***Quantile analyses*.** When considering just the identity effect as a function of deciles, the interaction reached significance in the analysis by participants, F_1 (1, 30) = 12.14, $p < .001$, MSE = 2513.84, $\eta^2_p = .34$, revealing that the identity effect gets larger in slower RTs, but not in the in the analysis by items, $F_2 < 1$. The by-participants identity effect as a function of deciles is displayed in Figure 5.

(Figure 5 about here)

Discussion

In Experiment 2, the standard distractor frequency effect was detected, with slower naming latencies for low frequency compared to high frequency words. The effect is mainly mediated by the μ parameter and, descriptively, this finding fits nicely with both the main accounts proposed in the literature. Slower distractors (i.e., low frequency words) would in fact allow blocking/exclusion operations to start later. In this perspective, one would expect the RT distribution for pictures presented with low frequency distractors to be uniformly shifted towards slower latencies. Of course, this should include the leading edge of the distribution (i.e., the first quantile), as was the case in the present experiment.

Quantile analyses revealed a tendency towards an increment of the distractor frequency effect in slowest trials. This might suggest that distractor frequency does not solely influence the point in time in which blocking/removal processes can start, but also the processes themselves, with low frequency words being more difficult to discard. The latter would be reflected in the different (i.e., more skewed) shape of the RT distribution for pictures presented with low frequency distractors. It is important to stress that none of the previously considered theoretical interpretations claim that blocking/removal processes themselves take more time for low frequency than for high frequency words. However, the slight increment detected in our experiment does not fully reach conventional levels of significance in the quantile analyses, and it is not reflected in a significant increase of the estimated τ parameter (note that the fit between the two measures is very good, as can be seen in Figure 4 and 5). As such, the present findings do not pose any problem to the available explanations of the distractor frequency effect. On the other hand, the fact that only the μ parameter is significantly influenced by the distractor frequency effect, which is indeed fully detectable even when analyses are limited to the fastest 10% of the RTs, strongly supports the current theoretical accounts, i.e. blocking/removal processes can start later for low frequency compared to high frequency words.

Experiment 3

The two experiments reported above indicated that the semantic interference and the distractor frequency effects are characterized by rather different distributional profiles. While the former effect is significantly reduced in faster RTs and grows in magnitude across the distribution, the latter is fully present since the faster tail, and its magnitude appears to be rather constant across the whole distribution. In an effort to further ascertain the consistency of these two profiles, in Experiment 3 we investigated the two effects within the same group of participants, in order to exclude the possibility that the two patterns outlined above are a mere by-product of between-group differences, rather than the reflection of different cognitive dynamics. In this experiment, the control conditions (i.e., the identity and the neutral conditions) were not implemented. As the results for these conditions were very consistent across previous experiments, we reasoned that it was not crucial to replicate them in a within-participants design. Further, their exclusion enabled us to keep the same number of observation per experimental cell, while holding constant the number of times in which pictures and distractors were presented with respect to the previous two experiments (see Apparatus and Procedure).

Method

Participants. Twenty-four undergraduate students from the University of Padova participated in this experiment. The criteria for their enrolment were the same as the other experiments, although some of these participants (10) took part for course credits.

Materials. The same pictures and the same distarctors (with the same pairings) as in Experiment 1 and 2 were used.[3] The construction of the experimental lists followed the same criteria and procedures illustrated for Experiment 1 and 2. The different conditions (semantically related, unrelated, high frequency, and low frequency distractor) were thus presented pseudo-randomly intermixed.

Apparatus and Procedure. Apparatus and procedure were the same as in previous experiments (this experiment took place in the same laboratory as Experiment 1).

Results

Trials in which errors (2%) or voice-key failures (0.5%) occurred were removed from the RTs analyses. The outliers' screening procedure (Van Selst & Jolicoeur, 1994) removed a further 3.69% of the data. Analyses for the sematic interference and the distractor frequency effects are reported separately.

Semantic interference effect.

Accuracy**.** The semantic interference effect was not significant, t_1 (23) = 1.63, p = .12, d = .36, t_2 (59) = 1.51, p = .16, d = .18. Mean proportions of correct responses are reported in Table 4.

Mean RTs**.** The semantic interference effect was significant, t_1 (23) = 5.64, $p < .001$, d = 1.17, t_2 (59) = 4.84, $p < .001$, d = .62. Mean RTs as a function of distractor type are reported in Table 4.

Ex-Gaussian analyses**.** The semantic interference effect was not significant with respect to the μ parameter, $t < 1$, and approached conventional significance for σ, t (23) = 1.98, p = .06, d = .4, with smaller estimates for the semantically related distractor condition. Semantic interference significantly affected the τ parameter, t (23) = 3.57, $p < .01$, d = .72. Mean estimated parameters are listed in Table 4.

Quantile analyses. Mean RTs as a function of deciles for pictures presented with semantically related and unrelated distractors are plotted in the upper-left panel of Figure 6. The interaction between the semantic interference effect and deciles was significant, F_1 (1, 33) = 10.58, $p < .01$, MSE = 2400.95, $\eta^2_p = .31$, F_2 (2, 120) = 9.59, $p < .001$, MSE = 3664.38, $\eta^2_p = .14$. The effect was 9 ms (95% CI [3, 15]) in the first decile (t_1 (23) = 3.12, $p < .01$, d = .64;, t_2 (59) = 1.5, p = .14, d = .2) and it progressively increased in the following deciles. The semantic interference effect as a function of quantiles is plotted in the lower-left panel of Figure 6.

Distractor frequency effect.

Accuracy. The distractor frequency effect was significant, t_1 (23) = 4.08, $p < .001$, d = .86, t_2 (59) = 2.77, p < .01, d = .36, with higher accuracy for pictures presented with high frequency distractors (Table 4).

Mean RTs. The distractor frequency effect was also significant in terms of mean RTs, t_1 (23) = 6.31, $p < .001$, d = 1.31, t_2 (59) = 7.31, $p < .001$, d = .94, with high frequency distractors yielding faster latencies (Table 4).

Ex-Gaussian analyses. Distractor frequency significantly affected μ, t (23) = 7.86, $p < .001$, d = 1.53, while it did not influence σ, $t < 1$, nor τ , t (23) = 1.68, p = .11, d = .37. Mean estimated parameters are listed in Table 4.

(Table 4 about here)

Quantile analyses. Mean RTs as a function of deciles for the high and low frequency distractor conditions are represented in the upper-right panel of Figure 6. When considering just the distractor frequency effect as a function of deciles, the interaction did not reach the conventional levels of significance, F_1 (1, 28) = 2.76, p = .1, MSE = 2938.93, $\eta^2_p = .11$, F_2 (2, 107) = 2.55, p =

.09, $MSE = 3703.95$, $\eta^2_p = .04$. Again, the effect was constantly present since the first quantiles, slightly increasing only in the last two deciles. When limiting the analysis to the first decile, the 26 ms effect (95% CI [19, 58]) was reliable both in the analysis by participants, t_1 (23) = 7.22, $p <$ .001, d = 1.44, and by items, t_2 (59) = 6.64, $p < .001$, d = .89. The distractor frequency effect as a function of deciles is displayed in the lower-right panel of Figure 6.

(Figure 6 about here)

Discussion

Experiment 3 replicated the main findings reported in previous experiments. The semantic interference effect appears to be mainly represented in the slower tail of the RTs distribution, and dramatically reduced in faster RTs. In contrast, the distractor frequency effect is reliably observed throughout the whole distribution and the effect does not seem to display dramatic changes in magnitude. Importantly, the different distributional profiles across the two effects have been detected within the same participants, suggesting that the distributional profiles are tightly linked to the different cognitive dynamics underlying the two effects, and not to between-group differences.

General Discussion

The investigation of the distributional features of the semantic interference and of the distractor frequency effects revealed an intriguing dissociation which provides further evidence for the commonly held idea that different cognitive dynamics underlie the two phenomena. More specifically, the bulk of the semantic interference effect seems to selectively involve the slowest RTs, and only marginally reflects a distributional shift (Experiment 1). In sharp contrast, the distractor frequency effect mainly assumes the shape of a distributional shift, where RTs for pictures presented with low frequency distractor are rather uniformly shifted towards slower latencies, compared to pictures presented with high frequency distractor (Experiment 2). Importantly, these different patterns have also been highlighted when both effects were manipulated within the same group of participants (Experiment 3), thus strengthening the idea that the different distributional profiles are reflecting the different cognitive dynamics underlying the effects.

The distributional shape of the semantic interference effect closely resembles the one highlighted for Stroop interference in manual variants of the paradigm (De Jong et al., 1999; Hommel, 1997; Pratte et al., 2010). As suggested by De Jong and colleagues (1997; see also Roelofs, 2008a), this distributional profile may reflect variability in attentional engagement during the task, with a reduced effect when attention is focused (fastest responses) turning into a larger effect for those trials in which attention is operating less effectively (slowest responses). Thus, this result seems to provide converging evidence for the idea that central attention is critical in resolving semantic interference. Indeed, attention seems relevant to such an extent that the semantic interference effect is dramatically reduced in those trials in which attention is thought to operate more efficiently, that is, in fastest trials.

Although (as outlined in the introduction) the model of lexical selection by competition and the most recent developments of the response exclusion hypothesis seem to agree on the notion that central attention is critical in resolving semantic interference (see also Roelofs, Piai, & Garrido Rodriguez, 2011; Shao, Meyer, & Roelofs, 2013), this latter claim has been questioned by empirical findings obtained within the psychological-refractory period (PRP) paradigm (e.g., Dell’Acqua, et al. 2007; Van Maanen, Van Rijn, & Taatgen, 2012). In the PRP paradigm participants are instructed perform two tasks (i.e., Task 1 and task 2) sequentially and the stimulus onset asynchrony (SOA) between the two tasks is manipulated. According to the central bottleneck model of attention (e.g., Pashler & Johnston, 1989), response selection requires the use of limited central attentional resources. When Task 1 and Task 2 are separated by short SOAs, those Task 2 processes requiring attentional resources have to be postponed, as these resources are being used to select the response for Task 1. In this context, it has been shown that when participants perform picture naming (Task 2) in close temporal proximity after a tone discrimination task (Task 1), the semantic interference effect is absent (Ayora et al., 2011; Dell’Acqua, et al. 2007; Van Maanen, Van Rijn, & Taatgen, 2012; for different arguments and results, see Piai & Roelofs, 2013; Piai, Roelofs, & Schriefers, 2014; Schnur & Martin, 2012). This result suggests that the resolution of semantic interference can occur while limited attentional resources are being dedicated to response selection for Task 1. Of course, this is more consistent with the idea that attention is not needed to resolve semantic interference in a PWI.

Importantly, Kleinman (2013) has emphasized that pictures and words are different in terms of processing automaticity, as it seems that word recognition can occur without central attention, at least up to the level of the orthographic lexicon (Reynolds & Besner, 2006), while lexical access for pictures would require attentional resources. This opens the possibility that only the distractor word can be processed during the response selection for the tone discrimination task, while lexical access for picture stimuli has to be postponed. Therefore, in a dual task where Task 2 is a PWI, semantic interference would not be detected because during the postponed lexical access for the picture stimulus, no actual influence is exerted by the distractor, as the latter has already been processed during Task 1 response selection.

In contrast, with respect to semantic interference, the distractor frequency effect is reflected mainly in a distributional shift. If low frequency distractors simply postpone the point in time in which the system can start the operations needed to discard the distractor, we can expect corresponding RTs to be rather uniformly shifted towards a slower range of RTs. Accordingly, we found that the distractor frequency effect is mediated solely by the μ parameter and that the effect is present in its almost full blown magnitude as soon as in the first decile, that is, in the fastest 10% of the trials.

From an empirical point of view, some inconsistencies can be highlighted between our results and previous studies. Considering the semantic interference effect, our results seem at odds with respect to what is reported by Piai and colleagues (2011), where the semantic interference effect influenced just the Gaussian component of the RT distribution. It has to be noted that a close inspection of Piai et al. (2011) data suggests that the effect, at least numerically, does increase in the slowest tail (see Piai et al., 2011, Figure 3; see also Piai et al., 2012). Qualitatively, results are not as different as they appear at first glance. Moreover, it also has to be stressed that in this previous work (as well as in Piai et al., 2012), distributional analyses were used in the context of more complex experimental manipulations (compared to the classical one addressed here) in order to evaluate whether the effect was moving in opposing directions across the distribution. In other words, the characterization of the distributional profile of the standard semantic interference effect was not the core of these studies.

When considering the distractor frequency effect, the distributional pattern we found in Experiment 2 and Experiment 3 contrasts with the one reported by Geng and colleagues (2014) in their quantile-analysis on data from the PWI and from the colour naming paradigm (jointly considered). More specifically, in their study the distractor frequency effect was shown to vary as a function of relative speed of the responses, with a negligible or null effect in fastest and slowest responses turning to a significant effect for modal ones. In their unified account for the PWI and the colour naming task, the authors proposed that the distractor frequency effect is absent in those instances in which the distractor processing starts when target processing has already finished, or in those trials in which the distractor processing is finished before any target processing has begun. For example, for fastest responses one can argue that responses to the targets were produced before distractors were processed (see also Hommel, 1997). However, when considering Experiment 2, not only was the distractor frequency effect present in our first quantile (suggesting that the distractors were always affecting target processing) but also both high and low frequency distractors yielded much slower latencies compared to the neutral condition. If these distractors were truly not processed in fastest responses, one would expect to find RTs at least similar to the neutral condition, in which a proper distractor is actually missing. In summary, Experiment 2 shows clear evidence that distractor processing was influential for the fastest RTs.

The reason for this discrepancy may lay in the fact that Geng et al. jointly analyzed different PWI and colour naming experiments in which they either did or did not obtain the distractor frequency effect. Because of this, we think that Geng et al.'s data do not actually permit determining whether differences in effects across quantiles are because of the speed of the response itself, or because different paradigms/experimental conditions are selectively represented in different portions of the RT distribution. Further - and more critically for the present study - their data cannot be used to describe the distributional shape of the distractor frequency effect in the PWI paradigm when it shows up.

Across the first two experiments, an intriguing finding has also been highlighted by the comparison between pictures presented with identity and neutral distractors. In sharp contrast with what is usually found in the Stroop task, the identity condition produces strong facilitatory effects that are significantly enhanced in the slower tail. The difference across paradigms with respect to the identity condition is not surprising. In a typical Stroop paradigm, few responses are repeated several times, while in the present experiment participants had to name 60 different pictures. Also, retrieving the name of a colour may be much easier than the retrieval of the name of pictures depicting more complex objects (e.g., an harpsichord). In other words, the finding that the PWI paradigm leaves more room for facilitation appears, at first glance, rather trivial. Nonetheless, these results may be important as they challenge any simple mapping between the μ parameter and response conflict, and the τ parameter and task conflict within the PWI paradigm (see the discussion section of Experiment 1).

Conclusions

Distributional analyses of the semantic interference and of the distractor frequency effects offered some important insights on the nature of these phenomena. First, the different distributional profiles of the two effects provide additional evidence to the idea that different cognitive dynamics underlie the two phenomena. Second, distributional analyses also provide further evidence in favour of two ideas shared across different theoretical perspectives on lexical access. More specifically, the distributional profiles highlighted in the present work are consistent with the ideas that (a) semantic interference critically relies on attentional process and (b) distractor frequency exerts an influence on the point in time in which the operations required to discard the distractor can actually start, rather than on the discarding processes themselves.

Supplemental Material

The materials used in experiments 1, 2 and 3 can be found at the address

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Footnotes

[1] We would argue that, although the intuitive appeal and the descriptive power of quantile-analyses are clear, this sort of analysis relies on larger degrees of arbitrariness compared to the parametrical approach. For example, the number of quantiles in which RTs are partitioned is selected by the researchers. This choice is sometimes theoretically motivated (e.g., Thomas, Neely, & O'Connor, 2012). Nonetheless, it may have an impact on the statistical results. In the present study, in line with other seminal works (e.g., Balota et al., 2008), we decided a priori to use deciles, which ensured a detailed description of the RTs distribution.

[2] In some trials, involuntarily produced noises activated the headset microphone ahead of time, thus terminating the presentation of the visual stimulus. Most of the times, this was unnoticeable since it occurred in a very close temporal proximity to the start of the utterance. For these trials, the onset latency was simply corrected off-line using the automatic onset detection procedure implemented in the Check Vocal software. In some other instances, however, the voice key error occurred so early that the response was disrupted and participants produced errors or simply were unable to give any response. These instances are those reported as voice-key errors.

[3] In previous experiments 4 words (castello - *castle*, granchio - *crab*, anatra - *duck*, zanzara - *mosquito*) were used both as semantically related/unrelated and high/low frequency distractors. These materials were kept equal in Experiment 3, therefore these words appeared 3 times for each participant, while other distractors appeared just twice (in case they were used as semantically related/unrelated distractors) or once (in case of high and low frequency distractors).

Figure Captions

Figure 1. Different ideal scenarios for the distributional features of a hypothetical effect. The first column represents RT distributions for two hypothetical experimental conditions (Cond. 1, and Cond. 2) as probability density functions. The second column represents the corresponding Quantile Plots of the effect (i.e., the difference between Cond. 2 and Cond. 1 as a function of Deciles). In all the three scenarios (one for each row), the overall mean for Cond. 1 (560) and 2 (620) were always the same, but while for Cond. 1 the hypothetical data point were simulated based on the same set of ex-Gaussian parameters in all the three scenarios ($\mu = 500$, $\sigma = 40$, $\tau = 60$), different sets of parameters were used to produce data points for Cond. 2. In row 1, ex-Gaussian parameters for Cond. 2 were $\mu = 560$, $\sigma = 40$, $\tau = 60$. In row 2, $\mu = 500$, $\sigma = 40$, $\tau = 120$. Finally, in row 3, $\mu = 530$, $\sigma = 40$, $\tau = 90$. Each scenario was simulated by generating 1000000 random samples of each distribution, where each sample is generated by summing a sample from a normal distribution with mean μ and standard deviation σ, and a sample from an exponential distribution with rate parameter = $1/\tau$ (see Johnson, Staub, & Fleri, 2012). Simulated values in each condition were then divided into 10 deciles, and averaged within deciles. In each decile, resulting means were subtracted (Cond. 2 – Cond. 1) and difference-scores were represented in Quantile Plots.

Figure 2. Experiment 1: Mean RTs for each experimental condition as a function of Deciles. Points represent empirical quantile-mean RTs and error bars the corresponding 95% confidence intervals. Lines represent quantile-mean RTs predicted by the estimated ex-Gaussian parameters. SR = semantically related distractors; SU = semantically unrelated distractors.

Figure 3. Semantic interference (SI) effect and identity effect as a function of Deciles in Experiment 1. Points represent empirical difference scores and error bars the corresponding 95%

confidence intervals. Lines represent difference scores predicted by the estimated ex-Gaussian parameters.

Figure 4. Experiment 2: Mean RTs for each experimental condition as a function of Deciles. Points represent empirical quantile-mean RTs and error bars the corresponding 95% confidence intervals. Lines represent quantile-mean RTs predicted by the estimated ex-Gaussian parameters. LF = low frequency distractors; HF = high frequency distractors.

Figure 5. Distractor frequency (DF) effect and identity effect as a function of Deciles in Experiment 2. Points represent empirical difference scores and error bars the corresponding 95% confidence intervals. Lines represent difference scores predicted by the estimated ex-Gaussian parameters.

Figure 6. Experiment 3: Mean RTs as a function of Deciles. The semantically related (SR) and unrelated (SU) distractor conditions are represented in upper-left panel, while the low (LF) and high frequency (HF) distractor conditions are represented in the upper-right panel. Semantic interference (SI) and distractor frequency (DF) effects as a function of deciles are plotted, respectively, in the lower-left and lower-right panels. Points represent empirical means and error bars the corresponding 95% confidence intervals. Lines represent means predicted by the estimated ex-Gaussian parameters.

Table 1

Properties of target-pictures used in all the experiments and distractor words used in Experiment 1 and 3 (SR/SU = semantically related/semantically related distractors) and in Experiment 2 and 3 (LF = low frequency distractors; HF = high frequency distractors).

Variables	Pictures	HF	LF	SR/SU
Frequency	16.24	146.35	2.48	14.53
AoA	-	2.84	3.05	-
Imageability	-	5.61	5.77	-
Concreteness	-	5.80	6.01	-
Letters	6.62	6.15	6.22	6.85
Phonemes	6.48	5.98	6.03	6.55
Syllables	2.83	2.68	2.67	2.78
Orth. N	5.17	5.73	4.42	4.02
MBF	-	10.85	10.75	-

Note. AoA = Age of Acquisition; Orth. N = orthographic neighbourhood density; MBF = mean bigrams frequency. Values of AoA, Imageability, and Concreteness were retrieved form the VARLESS database (Barca, Burani, & Arduino, 2002). Frequency values were retrieved from the COLFIS database (Laudanna et al., 1995) and standardized on one million occurrences. Orth. N values were calculated within the COLFIS database (Laudanna et al., 1995).

Table 2

Mean response time (RT), mean proportion of correct responses (ACC) and mean ex-Gaussian parameter estimates (μ, σ, τ) as a function of distractor type in Experiment 1.

Condition	RT	ACC	μ	σ	τ
SR	850 [806, 893]	.960 [.951, .969]	674 [649, 699]	59 [49, 69]	177 [154, 200]
SU	815 [773, 858]	.967 [.955, 979]	663 [640, 686]	53 [46, 60]	153 [128, 178]
SI effect	*35 [22, 46]*	*-.007 [-.016, .001]*	*11 [0, 22]*	*6 [-5, 16]*	*24 [11, 37]*
Neutral	665 [632, 698]	.984 [.977, .992]	564 [541, 587]	44 [38, 50]	101 [86, 117]
Identity	625 [588, 663]	.995 [.992, .997]	545 [519, 572]	49 [43, 59]	81 [63, 99]
ID effect	*40 [27, 52]*	*-.011 [-.018, -.003]*	*19 [7, 31]*	*-5 [-11, 2]*	*20 [8, 34]*

Note. SR = semantically related distractor; SU = semantically unrelated distractor; SI = semantic interference. ID = identity. 95% confidence intervals are reported within brackets.

Table 3

Mean response time (RT), mean proportion of correct responses (ACC) and mean ex-Gaussian parameter estimates (μ, σ, τ) as a function of distractor type in Experiment 2.

Condition	RT	ACC	μ	σ	τ
LF	759 [735, 783]	.981 [.973, .989]	658 [639, 677]	51 [43, 59]	102 [84, 119]
HF	728 [704, 752]	.984 [.976, .992]	635 [617, 653]	51 [45, 57]	94 [79, 108]
DF effect	*31 [23, 40]*	*-.003 [-.012, .006]*	*23 [15, 31]*	*0 [-6, 6]*	*8 [-3, 19]*
Neutral	639 [619, 658]	.987 [.982, .992]	557 [539, 575]	44 [41, 47]	82 [72, 92]
Identity	589 [563, 615]	.998 [.996, 1]	531 [508, 554]	45 [41, 49]	58 [47, 69]
ID effect	*40 [36, 64]*	*-.011 [-.016, -.006]*	*26 [15, 36]*	*-1 [-6, 5]*	*24 [13, 36]*

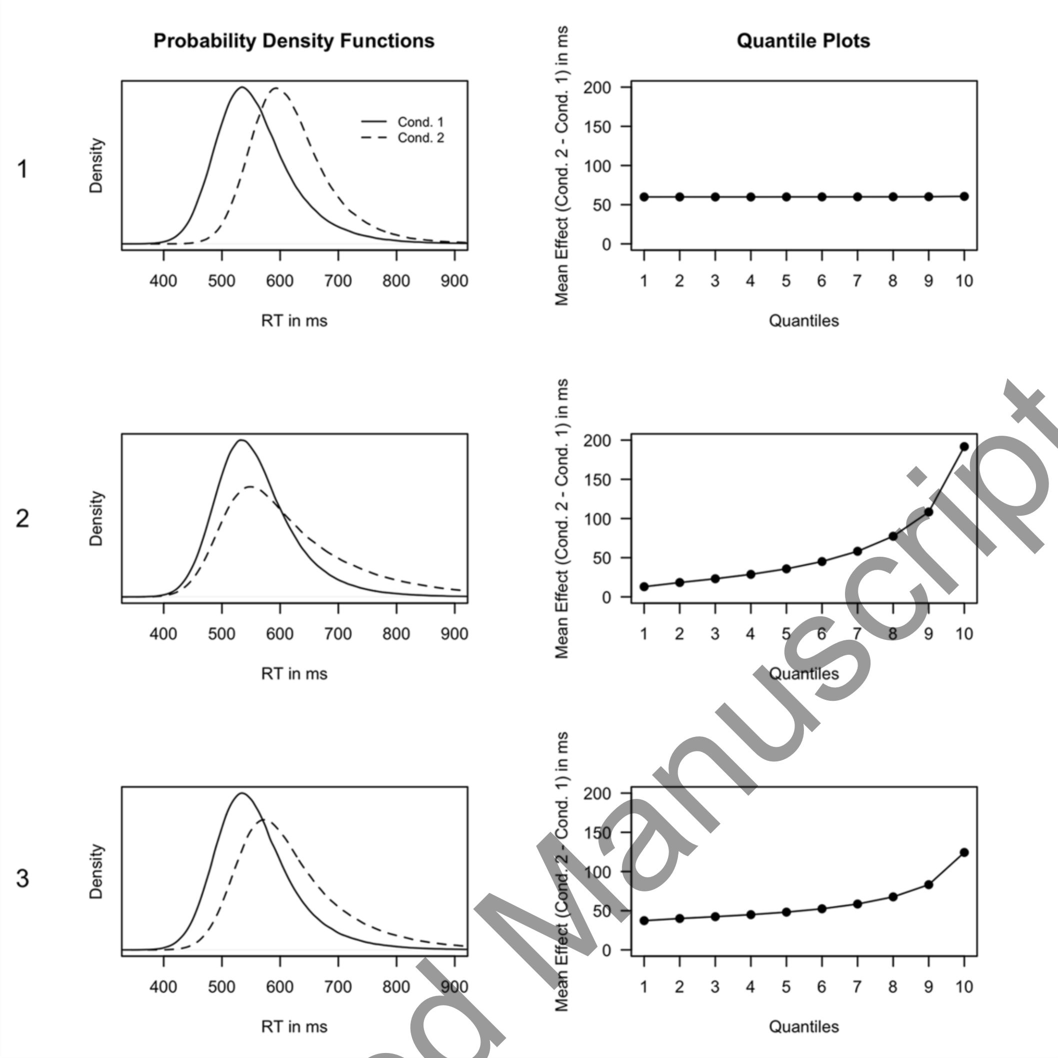
Note. LF = low frequency distractor; HF = high frequency distractor; DF = distractor frequency; ID = identity. 95% confidence intervals are reported within brackets.

Table 4

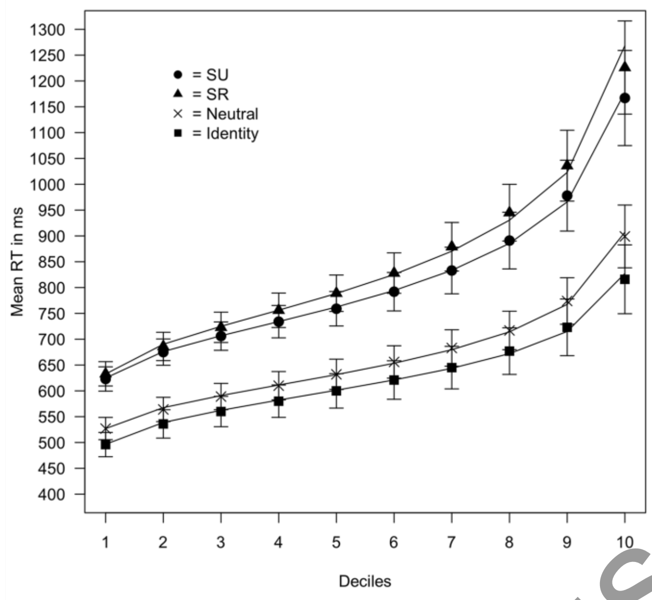
Mean response time (RT), mean proportion of correct responses (ACC) and mean ex-Gaussian parameter estimates (μ, σ, τ) as a function of distractor type in Experiment 3.

Condition	RT	ACC	μ	σ	τ
SR	730 [700, 760]	.984 [.978, .989]	612 [595, 629]	39 [34, 44]	119 [101,137]
SU	709 [681, 737]	.980 [.973, .987]	611 [592, 631]	43 [39, 48]	99 [83, 114]
SI effect	*21 [13, 29]*	*.004 [-.002, .01]*	*1 [-6, 8]*	*- 4[-9, 1]*	*20 [8, 32]*
LF	719 [692, 746]	.976 [.970, .983]	620 [602, 638]	41 [37, 45]	99 [83, 116]
HF	685 [658, 712]	.988 [.984, .991]	597 [581, 613]	42 [28, 46]	89 [73, 104]
DF effect	*34 [23, 45]*	*-.012 [-.019, -.005]*	*23 [17, 29]*	*-1 [-6, 4]*	*10 [-2, 22]*

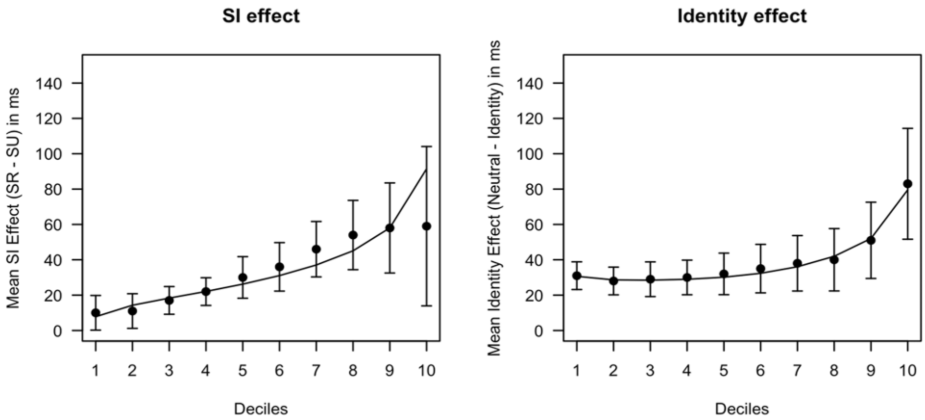
Note. SR = semantically related distractor; SU = semantically unrelated distractor; LF = low frequency distractor; HF = high frequency distractor; SI = semantic interference; DF = distractor frequency. 95% confidence intervals are reported within brackets.

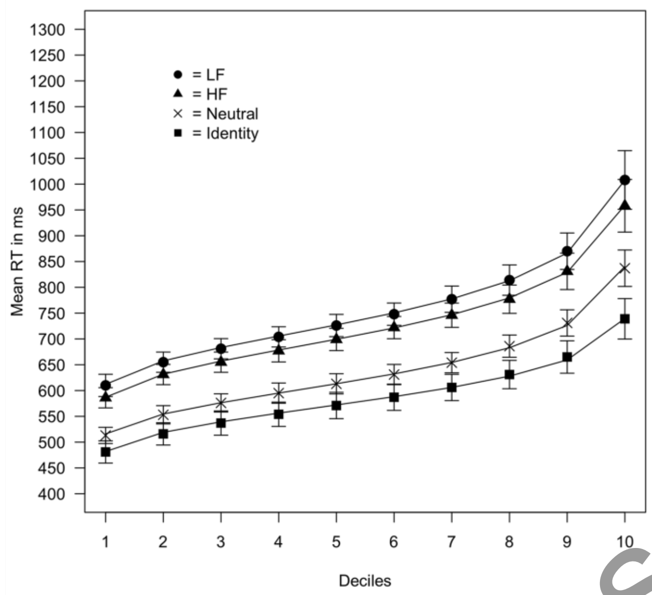


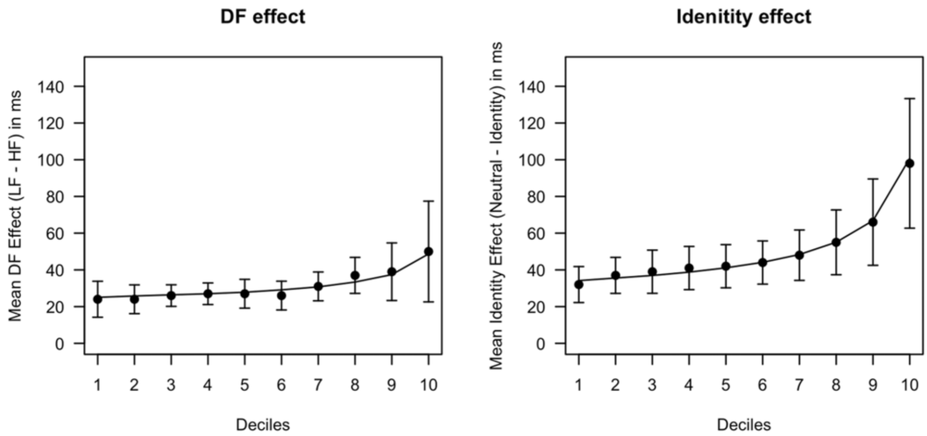
Probability Density Functions
Quantile Plots
1
2
3
Density
Cond. 1
Cond. 2
RT in ms
400 500 600 700 800 900
Mean Effect (Cond. 2 - Cond. 1) in ms
0 50 100 150 200
1 2 3 4 5 6 7 8 9 10
Quantiles

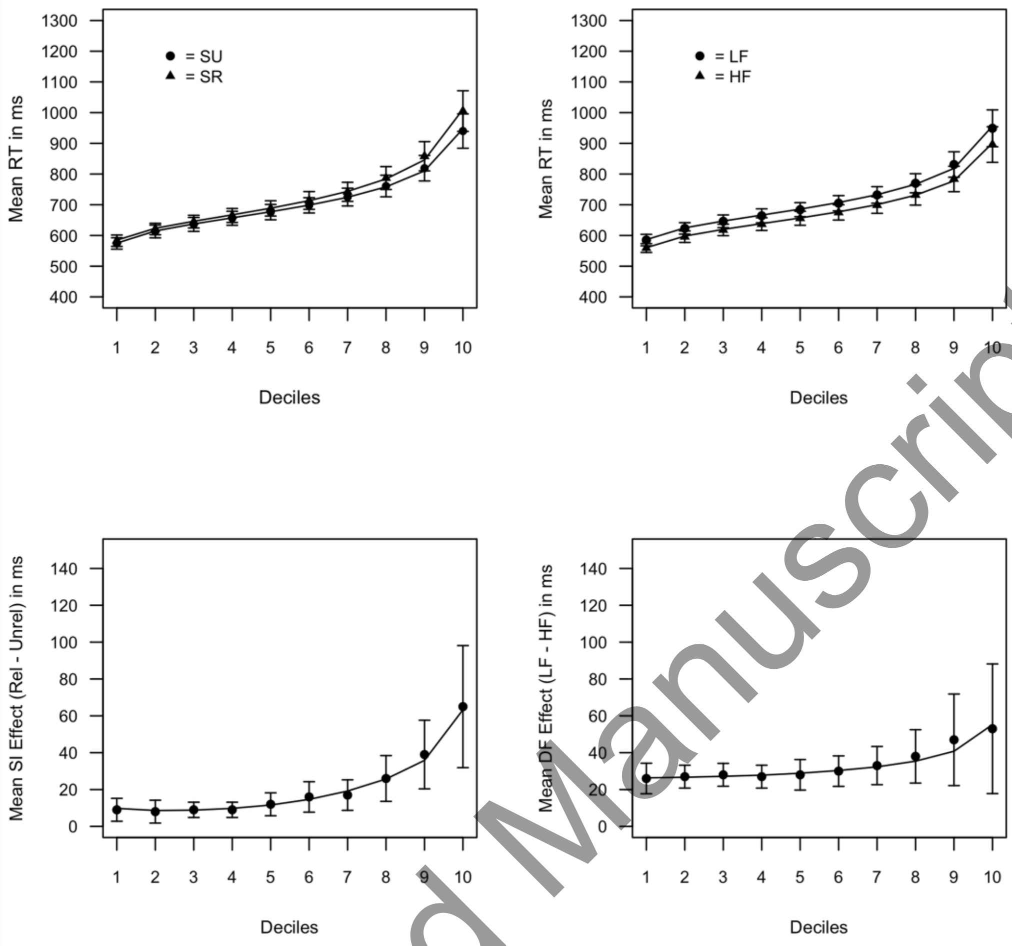


● = SU
▲ = SR
× = Neutral
■ = Identity
Mean RT in ms
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
1
2
3
4
5
6
7
8
9
10
Deciles


SI effect
Mean SI Effect (SR - SU) in ms
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10
Deciles
Identity effect
Mean Identity Effect (Neutral - Identity) in ms
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10
Deciles


1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
Mean RT in ms
● = LF
▲ = HF
× = Neutral
■ = Identity
1
2
3
4
5
6
7
8
9
10
Deciles


DF effect
Mean DF Effect (LF - HF) in ms
0
20
40
60
80
100
120
140
1
2
3
4
5
6
7
8
9
10
Deciles
Idenitity effect
Mean Identity Effect (Neutral - Identity) in ms
0
20
40
60
80
100
120
140
1
2
3
4
5
6
7
8
9
10
Deciles



Mean RT in ms
= SU
= SR
Deciles
Mean RT in ms
= LF
= HF
Deciles
Mean SI Effect (Rel - Unrel) in ms
Deciles
Mean DF Effect (LF - HF) in ms
Deciles