Introduction

Both the word-frequency effect and the stimulus visual quality (SQ) effect produce an overadditive interaction with the semantic priming effect (e.g., Becker, 1979; Balota, Yap, Cortese, & Watson, 2008). Word frequency and SQ, on the other hand, produce additive effects in lexical decision (e.g., Yap & Balota, 2007) and in pronunciation task, provided that both nonwords and words appear in the target-set (O’Malley & Besner, 2008). These results have been interpreted under the light of Sternberg’s additive factor logic (Sternberg, 1969), suggesting that word frequency and SQ are affecting two different and serially organized stages, while the semantic priming effect exerts its influence on both stages. However, the pattern is particularly challenging for current word-recognition models, since these rely heavily on cascaded and interactive activation. Indeed, the issue has generated a lively debate in the field (e.g. Besner & O’Malley, 2009; Borowsky & Besner, 2006; Plaut & Booth, 2006; Reynolds & Besner, 2004; Ziegler, Perry & Zorzi, 2009). Many studies have manipulated two of the three variables, but only one has jointly manipulated the three variables within the same experiment. Borowsky and Besner (1993) report the results from a lexical decision in which SQ (clear vs. degraded), word-frequency (manipulated as a continuous variable) and context (semantically related vs. semantically unrelated vs. nonword primes) were manipulated. The authors replicate the two-way interactions between semantic priming and word frequency, and the one between semantic priming and SQ. For the joint effects of SQ and word frequency, the authors focused on the results obtained when the target-word was primed by a nonword, confirming the traditional additive pattern. They did so “for the purpose of assessing the joint effect of Stimulus Quality and Word Frequency uncontaminated by Context” (Borowsky and Besner. 1993, pg. 826-827)”. However, when one considers the joint effect of frequency and SQ after word-primes, a different picture emerges: The additive pattern of frequency and SQ holds for targets primed by a semantically related word, but when the targets are primed by a semantically unrelated word, frequency and SQ exert overadditive effects.

The aim of the present research was to investigate how the presence of semantically related primes modulates the joint effect of SQ and frequency. Recent evidences (Balota et al., 2008; Thomas, Neely, & O’Connor, 2012) suggest that, for visually degraded stimuli, the reading-system retrospectively relies on prime-information to facilitate the processing of the degraded targets. Such a reliance on primes is particularly beneficial for the most difficult targets: A disproportional increase of the priming effect is detected at the slowest tail of the reaction time (RTs) distribution where, arguably, responses to the most difficult targets are located. How reliance on prime-information accounts for the results reported by Borowsky and Besner? If the presence of a related prime is particularly beneficial for the most difficult targets, then it would speed-up the responses to low-frequency degraded words. This would reduce the frequency effect detected on degraded targets, explaining the additive effects of SQ and frequency (the same frequency effect across stimuli’s visual quality). Differently, when an unrelated prime is presented the vain attempt to retrieve information from the prime disrupts target processing, particularly in the case of the most difficult targets (i.e., low-frequency words). In this scenario, the unrelated prime would slow down the responses to the low-frequency degraded words, increasing the frequency effect detected on the degraded items and explaining the SQ by frequency overadditive interaction.

To test this hypothesis, two experiments were run. In the first experiment, SQ, frequency and prime relatedness were jointly manipulated within participants. We expected to replicate the pattern reported by Borowsky and Besner (additive effects of frequency and SQ after related primes, interactive effects after unrelated primes). The account predicts that such a three-way interaction would be particularly evident in the slower tail of the reaction time distribution. In the Experiment 2, we tested a new prediction: we argue that the SQ by frequency interaction detected on targets preceded by unrelated primes is produced by the reliance on prime information that, for unrelated trials, is disrupting target processing. If that is the case, the overadditive interaction should revert to additive effects when participants are not relying on prime-information. To test this, in Experiment
2 the same targets as in Experiment 1 were presented preceded only by unrelated primes. In this context, participants had no reason to rely on prime-information.

**Methods**

*Materials.* One hundred and sixty prime-target pairs (80 high-frequency and 80 low-frequency targets) were selected from the Nelson, McEvoy, and Schreiber (1998) norms. Backward and forward association strength was controlled across high and low frequency prime-target pairs. Frequency values, as well as other variables, were taken from the English Lexicon Project Database (Balota et al., 2007). Onset phoneme, orthographic and phonological neighborhood density, length, and bigram-frequency were controlled across high and low frequency targets. Primes for high and low frequency targets were also balanced for frequency, length, orthographic and phonological neighborhood. Unrelated pairs were created by randomly reassigning primes to targets. One hundred and sixty nonwords were selected from the English Lexicon Projects Database (Balota et al., 2007). Words and nonwords did not significantly differ in length. However, following O’ Malley and Besner (2008), we selected nonwords that had significantly more orthographic neighbors than words, as well as higher bigram frequency (ps < .001). One hundred and sixty words were selected as primes for nonwords and were not different from the primes used for words on frequency, length, orthographic and phonological neighborhood. Prime relatedness and target SQ were counterbalanced across subjects.

*Procedure.* Sixty-four students (32 per experiment) participated to the study. They were asked to silently read the primes and to name the targets aloud. A microphone connected to a response-box recorded reaction times. Responses were coded (correct, incorrect or voice-key errors) on-line by the experimenter. Each trial started with a fixation point (+). After 1000 ms, the prime appeared on the screen for 100 ms, followed by a blank screen for the same duration. The target was then displayed until the voice-key detected a response. If no response was detected, the target disappeared from the screen after 5000 ms. A blank screen was presented for 1800 ms at the end of each trial. The letter strings were displayed in on a black background (Red, Green, Blue [RGB] 0, 0, 0). In the bright condition, targets were presented in RGB (65, 65, 65); in the dim condition, they appeared in RGB (5, 5, 5). Primes and the fixation point were always presented in the bright RGB (65, 65, 65).

In Experiment 1, SQ, word frequency and prime relatedness were manipulated within participants. In Experiment 2, only SQ and frequency were manipulated: all the targets, in fact, were preceded only by semantically unrelated primes (note that the unrelated prime-target pairs were the same across the two experiments).

**Results**

In Experiment 1, the three-way interaction between SQ, prime relatedness and frequency was significant ($F_1[1, 31] = 4.61$, MSE = .02, $p < .05$; $F_2[1, 158] = 4.26$, MSE = .047, $p < .05$). Planned comparisons indicated that the Frequency by SQ interaction was significant for the unrelated priming condition ($F_1[1, 31] = 5.52$, MSE = .022, $p < .05$; $F_2[1, 158] = 5.57$, MSE = .054, $p < .05$), but not for the related priming condition ($F_1 < 1$). The results replicate in a pronunciation task the pattern reported by Borowsky and Besner (1993) in a lexical decision. Coherently with the prime-reliance hypothesis, the three-way interaction was mainly located in the slowest tail of the RTs distribution. To formally test this, data form the slowest quintile of each condition were submitted to an ANOVA with SQ, prime relatedness and frequency as within-subject factors. The three-way interaction was significant ($F[1, 31] = 6.14$, MSE = .085, $p < .05$). Planned comparison revealed that the SQ by frequency interaction was reliable for unrelated trials ($F[1, 31] = 5.73$, MSE = .099, $p < .05$), but not for the related trials ($F[1, 31] = 1.19$, MSE = .062, $p > .2$). In Experiment 2, on the other hand, the two-way interaction between SQ and frequency was not significant ($F_1 < 1$). It is important to note that the same pairs of unrelated prime-targets produced a clear overadditive interaction in Experiment 1 (where these were presented along with semantically related pairs).
Discussion
The results suggest that the presence of related primes modulates the joint effects of SQ and frequency both at a trial-level (related vs. unrelated trials of Experiment 1) and as a list-wide factor (unrelated trials of Experiment 1 vs. unrelated trials of Experiment 2). In the context of Experiment 1, where primes represent a useful source of information, participants rely on primes to facilitate target processing in the visually degraded condition. Such a reliance on primes produces additive effects of SQ and frequency on related trials, where primes speed up the responses of the most difficult targets (degraded low-frequency words). For trials preceded by unrelated primes, the reliance on prime information disrupts the processing of low-frequency degraded words thus producing the SQ by frequency overadditive interaction. In Experiment 2 participants are presented just with unrelated prime-target pairs. We argue that in this context participants are not relying on primes (since these are not a useful source of information). Coherently with the prediction, SQ and frequency produces additive effects, suggesting that prime-reliance is a critical factor in explaining the modulation of the joint effects of SQ and frequency in the semantic-priming paradigm.

References