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Is lexical access autonomous? Evidence from combining overlapping tasks with recording event-related brain potentials

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ABSTRACT

In order to test the frequent assumption that lexical access in visual word recognition would proceed independent of central attention, the overlapping task paradigm has recently been employed with somewhat contradictory results. Here we combined overlapping tasks with the recording of event-related brain potentials to assess task load dependent modulations of lexical access in more detail. The study was carried out in Spanish with native Spanish speaking participants. They performed a high-priority pitch discrimination task followed by a visual lexical decision task, in which the difficulty of lexical access was manipulated by means of word frequency. Increasing task load by reducing the stimulus onset asynchrony between both tasks from 700 to 100 ms resulted in considerable slowing of lexical decisions. Word frequency effects were underadditive with the slowing induced by task overlap, indicating lexical access to take place although central attention was dedicated to the high-priority task. The effect of word frequency on the event-related potentials, used as electrophysiological indicator of lexical access, was much less delayed than the lexical decision responses in conditions of high task overlap, providing converging evidence for the independence of lexical access from central attention. On the other hand, this slight delay and an amplitude reduction of the effect with high task load show that lexical access may not be completely autonomous, but subject to some additional early source of interference.

1. Introduction

Reading is a highly overlearned every-day activity for many people, which appears to be effortless and independent of central attention. Experimental evidence for the autonomy of word processing comes from phenomena like the Stroop effect (Stroop, 1935), where reading colour words cannot be avoided although it may interfere with the task of naming the ink colour in which the word is printed. The idea of autonomous word processing has also been an implicit assumption in early models of visual word recognition (e.g. Forster, 1976; McClelland and Rumelhart, 1981; Morton, 1969) as well as in most modern ones (e.g. Coltheart et al., 2001; Plaut et al., 1996; Seidenberg and McClelland, 1989). A well-established

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Abbreviations: ERP, event-related potential; SOA, stimulus onset asynchrony; LDT, lexical decision task; T1, task 1; T2, task 2; RT1, reaction time for task 1; RT2, reaction time for task 2

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experimental procedure to examine the dependency of mental processes on central attention is the overlapping task paradigm (e.g. Keele, 1973; Pashler, 1984; Pashler and Johnston, 1989; Schweickert, 1978; Telford, 1931; Welford, 1952). Because evidence obtained in this paradigm concerning the autonomy of visual word recognition has yielded variable results (Allen et al., 2002; Cleland et al., 2006; Lien et al., 2006; McCann et al., 2000) we supplemented it in the present experiment with recordings of event-related brain potentials (ERPs). Next we will provide some background on overlapping tasks methodology and briefly discuss its application to visual word recognition and its combination with event-related potentials.

1.1. *The overlapping task paradigm*

In overlapping task experiments, two stimuli requiring separate responses, are presented in rapid succession. The delay between the stimuli, known as stimulus onset asynchrony (SOA), is varied across trials. Typically, response times to the first stimulus (RT1) are relatively unaffected by SOA, whereas those to the second stimulus (RT2) sharply increase when SOA is reduced. The standard account for this pattern of results assumes that some cognitive processes, presumably decision and response selection, need a mechanism which can only be dedicated to one task at a time, producing a processing bottleneck (Pashler, 1989; Pashler and Johnston, 1989; Welford, 1952). At short SOAs, this results in a waiting period, termed cognitive slack, for processes of Task 2 (T2) that need the bottleneck mechanism as long as this mechanism is busy with Task 1 (T1). Bottleneck models predict that increasing difficulty and thus time demands of T2-related processes that are functionally localized in or after the bottleneck will result in RT2 slowing, which is independent of SOA (see Fig. 1A). In this case, the effects of task overlap and processing difficulty on RT2 combine additively (Pashler, 1984; Pashler and Johnston, 1989; Schweickert, 1978). In contrast, difficulty manipulations of T2-related *pre*bottleneck processes should be fully reflected in RT2 only at long SOAs, while at short SOAs, the slowing should be absorbed into cognitive slack (see Fig. 1B). The effect of the difficulty manipulation should therefore decrease when SOA is reduced, resulting in an underadditive combination of the delays caused by task overlap and T2-difficulty (Pashler, 1984; Pashler and Johnston, 1989; Schweickert, 1978). These predictions, following the locus-of-slack logic (McCann and Johnston, 1992; Schweickert, 1978), allow to examine whether a mental process of interest depends on the availability of the central bottleneck if the process in question is included in T2 of an overlapping task experiment and its difficulty is manipulated.

Johnston et al. (1995) labeled the central bottleneck mechanism "central attention", distinguishing it from "input attention" assumed to operate on peripheral processes. Following these authors, the SOA manipulation in the overlapping task paradigm has often been understood as a manipulation of the availability of central attention for T2 processing. It is important to note that other accounts of central attention, characterizing it not as a bottleneck mechanism, but as a scarce resource, which can be gradually distributed across tasks (Kahnemann, 1973; McLeod, 1977; Tombu and Jolicoeur, 2003), can predict the same pattern of results, if participants perform T1 with priority and primarily devote all their attentional resources to this task.

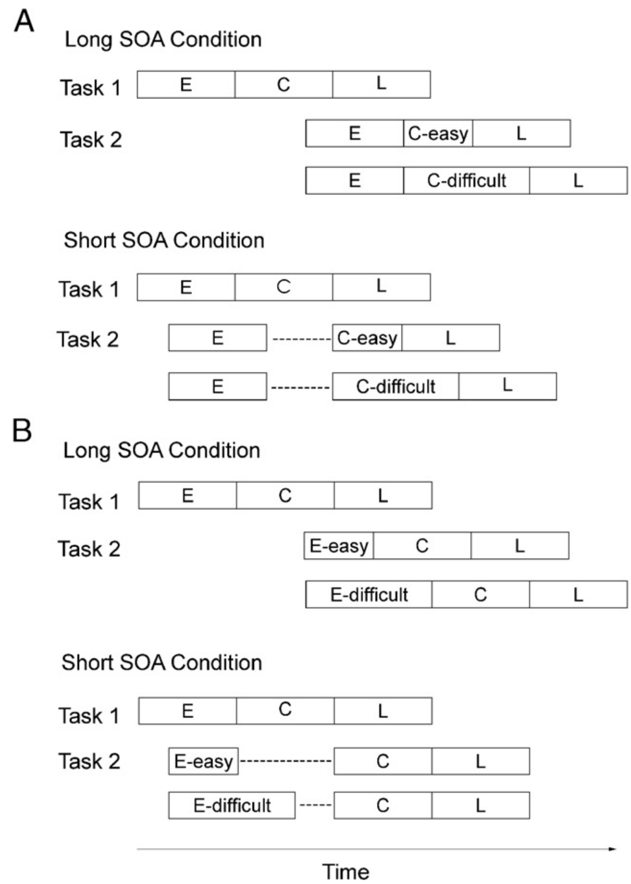

Fig. 1 – Depicted are early (E), central (C), and late (L) processes of task 1 (T1) and task 2 (T2) of an overlapping task paradigm, for long and short stimulus onset asynchrony (SOA) conditions, and either (panel A) a difficulty manipulation of a central T2 process, which needs the central bottleneck to proceed, with the difficulty effect predicted not to differ between SOA conditions, or (panel B) a difficulty manipulation of an early T2 process, located before the central bottleneck, with the difficulty effect predicted to be absorbed into cognitive slack (- - - -) in the short SOA condition.

1.2. *Visual word recognition in overlapping tasks*

In the present experiment, we included a visual lexical decision task (LDT) as T2 in an overlapping task paradigm and manipulated the difficulty of lexical access by means of word frequency. Following the locus-of-slack logic (McCann and Johnston, 1992; Schweickert, 1978), the combination of the effects of word frequency and SOA on RT2 allowed to examine whether lexical access depends on central attention. In the following, we will review the basic findings about word frequency effects on reaction time (RT) and available evidence obtained from overlapping task paradigms.

High frequency words are recognized faster and more accurately than low frequency words (Forster and Chambers, 1973; Howes and Solomon, 1951; Rubenstein et al., 1970). This has often been interpreted to indicate that word frequency influences lexical access in visual word recognition (Broadbent, 1967; Forster and Chambers, 1973; Monsell, 1991; Monsell et al., 1989; Morton, 1969), with lexical access being more difficult for low frequency words. Nevertheless, there is some debate about an additional postlexical influence of word frequency on decision processes in the LDT (Balota and Chumbley, 1984). In general, the effect has been implemented at precentral processing stages in models of visual word recognition: In serial-search models (e.g. Forster, 1976) word entries are ordered by frequency, search starting with the most frequent words. In localist interactive activation models (e.g. Morton, 1969; McClelland and Rumelhart, 1981) levels of resting activation are higher for high frequency than for low frequency words. In distributed interactive activation models (e.g. Plaut and McClelland, 1993), connection weights are optimized by training and the amount of training that a specific word receives is obviously related to its frequency.

Several recent studies have investigated the dependency of visual word processing on central attention by including it within T2 (most often a visual LDT) of an overlapping task paradigm, manipulating its difficulty by means of word frequency. If visual word processing is autonomous, the effect of word frequency should interact underadditively with SOA. However, McCann et al. (2000) who combined a pitch discrimination task with either an LDT or a naming task, to test this prediction, found additivity. In contrast, Allen et al. (2002), combining a visual T1 with a visual LDT, found a significant underadditive interaction, which was more pronounced for older than younger adults. Subsequently Lien et al. (2006) aimed at distinguishing whether parallel processing depends on T1 modality or on age and had younger and older adults perform a T2 LDT preceded by either a visual or an auditory T1. They found underadditivity of SOA and word frequency independent of T1 modality, but dependent on age, with evidence for parallel processing only in older adults. Lien et al. explained the restriction of this parallel processing superiority on lexical processing, as revealed by a nonlexical T2, with the greater cumulative experience of older adults with lexical processes. However, Cleland et al. (2006) had young adults perform a pitch discrimination T1 combined with a visual LDT and found underadditivity of word frequency and SOA, providing evidence for parallel processing in conditions very similar to those of the McCann et al. (2000) study. The authors attributed the discrepancy of the results to low statistical power in the McCann et al. study, an explanation receiving some support from the nonsignificant trend towards underadditivity in the data of McCann et al. and from the much larger word frequency effect reported by Cleland et al. (2006). Evidently, the available results are heterogeneous and further investigation of the issue seems desirable.

1.3. ERPs in overlapping tasks

While RTs reflect contributions from virtually all processing stages, ERPs provide a continuous and in some respects more specific measure of the processes between stimulus presentation and response. Therefore, ERPs are well-suited for localizing the effect of a given experimental manipulation within the processing stream. In the following, we will first describe the effects of word frequency on the ERP and their functional interpretation and then show how ERPs can be used in combination with the overlapping task paradigm to assess the effects of task overlap on the time course of cognitive processes.

Some recent studies have reported very early effects of word frequency on the ERP, with lower amplitudes for high frequency words starting at about 160 ms (Hauk and Pulvermüller, 2004), 132 ms (Sereno et al., 1998), or even 110 ms (Hauk et al., 2006) already. However, these very early effects have been small and the many studies failing to detect word frequency effects at such early latencies (e.g. Allen et al., 2003; Barber et al., 2004; Rugg, 1990; Van Petten and Kutas, 1990) suggest that they might be hard to obtain reliably. This is presumably even more true when recording ERPs in a dual-task setting entailing additional noise. More consistent word frequency effects have been observed from around 300–350 ms onwards, with low frequency words involving more negativity than high frequency words (Allen et al., 2003; Barber et al., 2004; Hauk et al., 2006; Hauk and Pulvermüller, 2004; Rugg, 1990; Sereno et al., 1998; Van Petten, 1993; Van Petten and Kutas, 1990, 1991). The general morphology of the waveforms in this time window is characterized by the N400 component, a negative deflection peaking around 400 ms which has been related to lexical search and semantic processes. The N400 is modulated by several variables affecting lexical–semantic processing, e.g. semantic priming, word repetition, and expectancy of written words, with more negativity for unrelated, unrepeated and unexpected target words, respectively (Bentin, 1987; Bentin et al., 1985; Boddy, 1986; Holcomb, 1988; Nagy and Rugg, 1989; Rugg, 1985, 1990). The N400 is closely followed or even partly overlapped by the positive-going P3 component, indicating stimulus identification and categorization processes (Kutas et al., 1977; Magliero et al., 1984). The components can be dissociated, e.g. by specific task requirements (Roehm et al., 2007), but sometimes it has been difficult to unequivocally disentangle whether effects observed in this time window are due to N400 or P3 modulations, or both (Bentin, 1987; Holcomb, 1988; Rugg, 1985, 1990), and this also holds true for word frequency effects. Although most researchers assume them to be caused by an increased N400 amplitude for low frequency words (e.g. Barber et al., 2004; Rugg, 1990; Van Petten and Kutas, 1990, 1991), others have related them to the P300 being increased and peaking earlier for high frequency words (Polish and Donchin, 1988). Functionally, however, ERP word frequency effects have been interpreted as electrophysiological indicators of lexical access independent of these ambiguities (e.g. Barber et al., 2004; Polish and Donchin, 1988).

Word frequency effects on the ERP thus provide us with a tool to monitor the time course of lexical access and its modulation by the availability of central attention. If lexical access depends on central attention and cannot take place during cognitive slack, the effect should be delayed by shortening SOA by about the same amount as the response times on the lexical decision task. If it can take place during cognitive slack, that is, while central attention is unavailable, there are two possible outcomes. If lexical access is completely autonomous, it should be independent of task overlap, and its electrophysiological indicator should not be influenced by the

SOA. On the other hand, even if lexical access does not depend on central attention, it may be subject to some additional, early source of interference, causing a slowdown in conditions of high task overlap. In this case, the ERP word frequency effect should be delayed in the short, compared with the long SOA condition, but the delay should be more modest in size than the delay in behavioural responses to the lexical decision.

SOA effects on electrophysiological indicators of cognitive processes may not only concern their time course but also their amplitude. An amplitude reduction of ERP effects in short relative to long SOAs may be interpreted as a reduction of the amount of cognitive resources dedicated to the underlying processes, such as lexical access.

In the overlapping task paradigm, brain waves elicited by the stimulus of interest, in our case the LDT stimulus, overlap with the ERPs to stimuli and responses of T1. But, as electric fields of several sources combine linearly without interacting (e.g. Nuñez, 1981), it is possible to isolate the effect of a particular experimental factor (e.g. word frequency) by a subtraction procedure, which eliminates the invariant overlapping activity. In our study, for example, the effect of word frequency on the ERP was isolated by subtracting the ERPs to high frequency words from those to low frequency words within each experimental condition. This way, it was possible to identify for each SOA the point in time after stimulus presentation, at which processes sensitive to word frequency, supposedly lexical access, occurred.

Several previous studies have used this approach, pioneered by Osman and Moore (1993). In the language domain Hohlfeld et al. (2004b) and Hohlfeld et al. (2004a) elicited N400 components to spoken nouns as T2 stimuli that were synonymous or nonsynonymous to a preceding noun. At short SOA N400 latency was delayed relative to long SOAs by about the same amount of time as was RT2, indicating that the N400 generating processes are either part of the central bottleneck or follow it. In a non-linguistic overlapping task study – that is relevant for present purposes – Luck (1998) focused on the P3 wave. He found it slightly reduced in amplitude and delayed in the short SOA condition but less than was RT2. Therefore he concluded that the processes underlying the P3 component are functionally localized before the central bottleneck, but are somewhat slowed by an additional source of interference earlier in the processing stream. The finding of a delay of the P3 component modest in size as compared to the delay in RT2 has been replicated by Arnell et al. (2004), and Dell'Acqua et al. (2005). In addition, a recent study by Brisson and Jolicoeur (2007) reports the same pattern for the sustained posterior contralateral negativity (SPCN), held to reflect visual working memory activity (Klaver et al., 1999), also suggesting some dual-task interference prior to the postponement primarily responsible for the delay in RTs.

1.4. *The present experiment*

The present experiment aimed at further investigating whether lexical access in visual word recognition proceeds as autonomously as often assumed and implemented in most models of visual word recognition. To this end, we used a paradigm very similar to that used by McCann et al. (2000) and Cleland et al. (2006), combining a high-priority pitch discrimination T1 and a visual LDT as T2, with difficulty of visual word recognition being manipulated by means of word frequency. Overlap between both tasks was either high (SOA 100 ms) or low (SOA 700 ms). The participants were young adults, an age group, which had yielded variable results in previous reports. If lexical access depends on central attention, we predicted additivity of the effects of SOA and word frequency on RT2, and a delay of the ERP word frequency effect in the short SOA condition similar in size to the delay in RT2. On the other hand, if lexical access can take place without central attention, we expected an underadditive interaction of the effects of SOA and word frequency on RT2. ERP recordings allowed to further differentiate between complete autonomy of lexical access, and lexical access being slowed in conditions of high task overlap due to an additional source of interference early in the processing stream. For complete autonomy we predicted the effect of word frequency on the ERP to be independent of SOA, whereas an additional early interference should result in the effect being delayed in the short SOA condition, but less so than RT2.

2. Results

2.1. *Data analysis*

After excluding trials with pseudoword stimuli, reaction times (RTs) and error rates (ERs) of both tasks as well as ERP amplitudes were submitted to repeated measures ANOVAs including the factors SOA (100 vs. 700) and word frequency (high vs. low).

ERP amplitude means were collapsed for clusters of electrodes in the left anterior (F1, F3, C1A, and C3A), right anterior (F2, F4, C2A, and C4A), left central (C1, C3, C1P, and C3P), right central (C2, C4, C2P, and C4P), left posterior (P1, P3, P1P, and P3P) and right posterior (P2, P4, P2P, and P4P) region, roughly corresponding to regions of interest (ROIs) used in previous reports of word frequency effects on the ERP (e.g. Barber et al., 2004). For analysis of ERP amplitudes, the additional within-subject factors region (anterior, central, posterior) and hemisphere (left vs. right) were included in the ANOVAs. Mean amplitudes were calculated in the ERP waves for successive segments covering the time window from 100 to 800 ms after presentation of the LDT stimuli (100–200 ms, 200–350 ms, 350–500 ms, 500–650 ms, and 650–800 ms).

After applying a 7 Hz low pass filter to attenuate high frequency noise, difference waves were calculated in the left posterior region, where the word frequency effect was greatest, between ERPs to high and low frequency words. Peak latencies and peak amplitudes of these difference waves were determined as the minimum voltage within an interval of 100–800 ms after presentation of the LDT stimuli. These parameters were determined in grand mean jackknife averages (Ulrich and Miller, 2001) and submitted to a one-factorial ANOVA with repeated measures on SOA; the resulting *F*-

values were corrected accordingly. If appropriate, degrees of freedom were corrected according to Huynh and Feldt (1976).

2.2. Pitch discrimination performance

Task overlap did not significantly affect RTs for the foot responses, $F\ (1, 23)=3,2$, $p=.087$, with mean RTs of 716 ms in the short and 758 ms in the long SOA conditions. ERs were significantly higher in the short SOA conditions, $F\ (1, 23)=10.56$, $p<.01$, with $M=11.3\%$ compared to 8.7% in the long SOA conditions.

2.3. Lexical decision performance

As is common for the second task in an overlapping tasks experiment, RTs strongly decreased as SOA increased, with mean RTs of 1190 and 805 ms for SOA 100 and 700, respectively, $F\ (1, 23)=349.28$, $p<.001$.

RTs were shorter for high than for low frequency words, $F\ (1, 23)=34.46$, $p<.001$, replicating the typical word frequency effect on RTs. This effect interacted underadditively with SOA, $F\ (1, 23)=4.75$, $p<.05$, with a 62 ms difference between high and low frequency words in the long and 23 ms in the short SOA condition (see Fig. 2). Post-hoc comparisons revealed the word frequency effect to be highly significant for long SOA, $F\ (1, 23)=46.82$, $p<.001$, whereas at short SOA it failed significance, $F\ (1, 23)=3.16$, $p=.178$.

ERs for low frequency words were significantly higher than for high frequency words, replicating the typical word frequency effect in ERs, $F\ (1, 23)=62.90$, $p<.001$ ($M=10.6$ and 21.3% for high and low frequency words, respectively). There was a significant interaction of word frequency and SOA, $F\ (1, 23)=9.11$, $p<.01$. ERs for high frequency words were higher in the short than in the long SOA condition ($M=12.0$ and $M=9.2\%$, respectively), whereas the reverse was true for low frequency words ($M=19.9$ and 22.8% for short and long SOAs, respectively), resulting in a word frequency effect in ERs that decreased with SOA (*M Diff* [low frequency−high frequency]=7.9 and 13.6% for short and long SOAs, respectively).

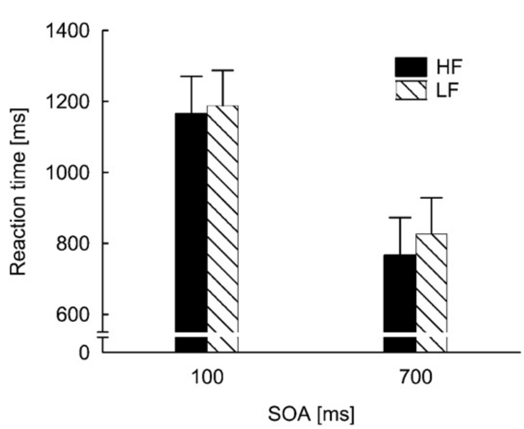

Fig. 2 – Mean reaction times in the lexical decision task as a function of stimulus onset asynchrony (SOA) and word frequency. Error bars represent standard error. HF = high frequency words; LF = low frequency words.

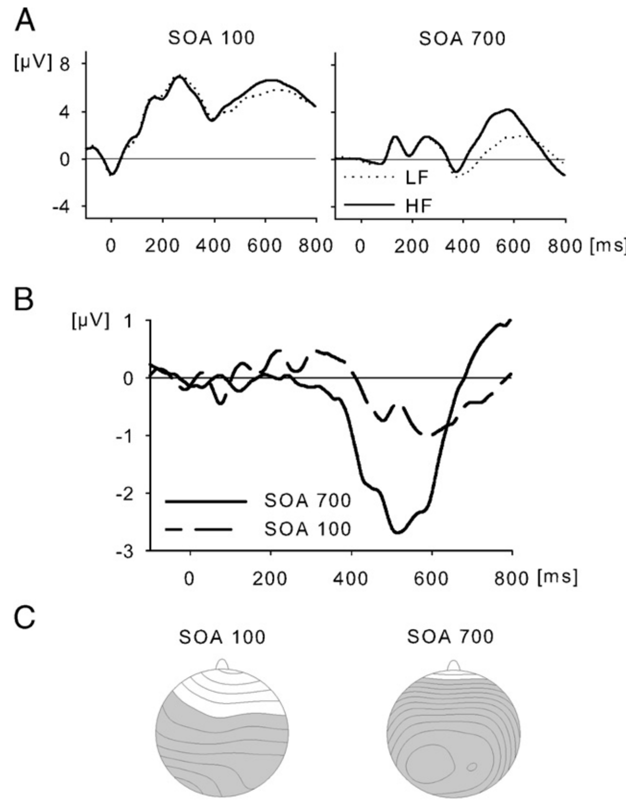

Fig. 3 – Word frequency effects on the event-related potentials (ERPs) for short and long stimulus onset asynchrony (SOA) conditions. Panel A depicts ERP wave shapes at the left posterior cluster in response to high frequency (HF) and low frequency (LF) words at both SOAs. Panel B shows the difference waves between ERPs to HF and LF words (LF – HF) at the left posterior cluster for both SOAs. Please note that negativity is plotted downwards. Panel C depicts the scalp topography of these difference waves at their peak for both SOAs (592 ms for SOA 100, and 516 ms for SOA 700). Negative regions are depicted in gray; contour spacing represents amplitude differences of 0.2 μV.

2.4. ERP data

Fig. 3 depicts ERPs evoked by high frequency words and low frequency words as well as the difference waves between these conditions, for both SOAs. As can be seen, ERPs for low frequency words were more negative than those for high frequency words from about 350 ms on, the difference being smaller and seemingly delayed for short compared to long SOA.

The main results of the ANOVAs of ERP amplitudes are summarized in Table 1. ANOVA confirmed significant effects of word frequency and significant SOA x Word Frequency interactions in the two time segments from 350 to 650 ms. Post-hoc tests revealed the word frequency effect to be significant for SOA 700 in both time segments, $F\ (23, 1)=8.6$, $p<.05$ in the 350–500 ms segment and $F\ (23, 1)=17.1$, $p<.001$ in the 500–650 ms segment, whereas for SOA 100, it failed significance, $F<1$ in the 350–500 ms time window, and $F=2.1$, $p=.32$ in the 500–650 ms window. The visual impression of the amplitude reduction in the short SOA condition was further

Table 1 – *F* values and significance levels from the analysis of variance of event-related brain potential amplitudes in specified time segments

Source	*df*	Time segments (ms)				
		100–200	200–350	350–500	500–650	650–800
SOA	1, 23		5.3 *			
WF	1, 23			6.3 *	13.7 **	
SOA × WF	1, 23			5.2 *	9.3 *	

Note. SOA = stimulus onset asynchrony; WF = word frequency.
* $p<.05$.
** $p<.01$.

confirmed by the analysis of the effect's peak amplitude, which was significantly reduced in the short compared to the long SOA condition, *Fcorr* (23, 1) = 12.3, $p<.01$, with a mean peak amplitude of −2.6 μV for SOA 700, and of only −1.1 μV for SOA 100. In addition, analysis of the peak's latency revealed it to be significantly delayed in the short compared to the long SOA condition, *Fcorr* (23, 1) = 10.8, $p<.01$, with mean peak latencies of 516 and 592 ms for SOA 700 and 100, respectively.

In the 350–500 ms segment, the word frequency effect was qualified by an interaction with the hemisphere factor, *F* (23, 1) = 4.6, $p<.05$. Further testing showed the effect to be significant in the left hemisphere, *F* (23, 1) = 7.8, $p<.05$, but not in the right hemisphere, *F* (23, 1) = 4.7, $p=.082$. In the 500–650 ms time window, word frequency interacted with the region factor, with post-hoc tests showing the effect to be significant in posterior regions, $F=16.5$, $p<.001$, and in central regions, $F=14.1$, $p<.01$, but not in anterior regions, $F=4.1$, $p=.18$. In the 200–350 ms window, there was a main effect of SOA, $F=5.3$, $p<.05$, presumably due to differences between SOA conditions concerning overlapping T1 ERPs.

3. Discussion

The present study sought evidence about the autonomy of lexical access in visual word recognition. We combined recording ERPs with an overlapping task design, manipulating the availability of central attention for visual word processing. A high-priority pitch discrimination T1 overlapped to a higher or lesser degree (SOA 100 vs. 700 ms) with a lexical decision task (LDT). Word frequency was manipulated in the stimulus set for the LDT and its effect on the ERPs provided an electrophysiological indicator of lexical access and its time course as a function of temporal overlap with the primary pitch discrimination task.

As usual for a high-priority T1 there was not much of an influence of SOA on RTs during pitch discrimination. There was a trend for slower responses in the long SOA condition, though. On the other hand, ERs were significantly higher in the short SOA condition, raising the possibility of a trade-off between RTs and ERs in this task.

Responses to the secondary LDT, on the other hand, were considerably slower in the short SOA condition than in the long SOA condition, presumably due to postponement of processes associated with the LDT which require central attention, as for example decision and response selection processes (e.g. Pashler and Johnston, 1989).

RTs and ERs for the LDT showed high frequency words to be recognized faster and more accurately than low frequency words, replicating the typical word frequency effect. As explained in the introduction, this effect has been interpreted as being due to lexical access taking place easier and faster for high frequency words (Broadbent, 1967; Forster and Chambers, 1973; Monsell, 1991; Monsell et al., 1989; Morton, 1969).

The primary question was whether lexical access is subject to postponement while central attention is devoted to T1 or whether it can proceed even when central attention is unavailable. For this question it is of relevance whether the effect of word frequency is absorbed into cognitive slack in the short SOA condition or whether it combines additively with SOA. The results show an underadditive interaction of SOA and word frequency, with a highly significant 62 ms word frequency effect in the long SOA condition dropping to a small and nonsignificant 23 ms effect in the short SOA condition (see Fig. 2). Clearly, the word frequency effect was absorbed into cognitive slack, indicating, as explained in the introduction and following well-established reasoning (Pashler, 1984; Pashler and Johnston, 1989; Schweickert, 1978), that lexical access can proceed while central attention is unavailable.

It is important to note, however, that the result of an underadditive interaction between SOA and word frequency cannot be taken as definitive evidence for complete autonomy of lexical access. Such an interaction clearly shows that the process did not come to a halt while central attention was unavailable. However, the underadditive interaction is compatible not only with lexical access proceeding completely autonomously; it is also compatible with lexical access being somewhat slowed down in conditions of high task overlap due to an additional source of interference prior to any interference caused by the unavailability of central attention. Judging from the SOA effect on RT2 the duration of the cognitive slack in the present conditions is about 385 ms. This easily allows for the absorption of the 62 ms word frequency effect seen at the long SOA, even if lexical access is slower with high task overlap. We can conclude from the RT pattern that lexical access has taken place by the end of cognitive slack in the short SOA condition. However, it is not possible to infer whether it has taken place at the same speed and with the same intensity as in the long SOA condition. More pertinent information on this question is provided by the ERP recordings.

Word frequency affected the ERP in the segments from 350–500 and 500–650 ms (see Table 1). Replicating previous findings (Allen et al., 2003, Barber et al., 2004, Van Petten, 1993, Van Petten and Kutas, 1990, 1991), ERPs to low frequency words were more negative than those to high frequency words on left parietal electrode positions. If we accept this ERP effect as electrophysiological indicator of lexical access, as has been suggested (e.g. Barber et al., 2004), it allows to examine task load dependent modulations of the time course and intensity of lexical access. The peak latency analysis revealed the effect to be delayed in the short compared with the long SOA condition, but its 76 ms delay was modest in size as compared to the 385 ms delay in RT2. As explained in the introduction, such a comparatively slight delay of actually less than 25% of the RT delay, indicates that the underlying processes can proceed during cognitive slack, albeit somewhat slowed.

Therefore the ERP results provide converging evidence for lexical access taking place during cognitive slack, that is, when central attention is dedicated to T1. On the other hand, the slight delay also shows that lexical access did not proceed completely autonomously and independent of task overlap. The process seems to be slowed down by additional task load.

In addition, the peak amplitude analysis showed the word frequency effect to be significantly reduced in the short compared to the long SOA condition. At short SOA the effect did not even reach significance. As explained in the introduction, such an amplitude reduction may be interpreted to indicate a depletion of necessary resources, reinforcing the notion that lexical access does not proceed completely autonomously.

Taken together, the absorption into cognitive slack of the difficulty manipulation of lexical access by means of word frequency and the comparatively modest delay of the word frequency effect on the ERP in the short SOA condition, converge on indicating that lexical access can take place although central attention is dedicated to another task. At the same time, this modest but significant delay as well as the amplitude reduction of the electrophysiological indicator of lexical access, shows that lexical access is not completely autonomous. Instead, there seems to be an additional source of interference causing it to proceed at a slower pace and with decreased intensity in conditions of high task overlap.

What could cause this slowing of lexical access and the reduction of its intensity? In the following, we will discuss two possible reasons: First, participants might inhibit visual word processing structures in order to optimize T1 performance. Second, central attention is possibly not the only resource for which tasks may compete. Specifically, auditory processing resources may be required both for the auditory pitch discrimination task and for phonological recoding of the visually presented words.

There is evidence suggesting that participants inhibit T2 processing structures in advance of each trial to optimize dual-task performance (De Jong, 1995). The possibility of a visual word recognition network, working stimulus-driven and self-organizing, but which participants can inhibit in order to minimize interference with T1 processing, was then discussed by McCann et al. (2000). This assumption seems to fit well with the tendency for stronger underadditivity, and hence more parallel processing, in older adults, reported by Allen et al. (2002) and Lien et al. (2006), because the capacity for inhibiting task-irrelevant processes appears to decline with age (Hasher et al., 1991). Possibly, the ability to follow the instruction to optimize T1 performance on the cost of T2 performance might decline with age in a similar way.

A second account for the apparent prebottleneck interference suggests that both the tone discrimination task and the visual LDT draw on auditory processing resources, with resource depletion slowing lexical access. This account makes the assumption that visually presented words are phonologically recoded, held by dual route models of reading (e.g. Coltheart et al., 1993; Coltheart et al., 2001) and by authors defending an early and mandatory activation of phonology in reading words (e.g Frost, 1998; Lukatela et al., 2002; Pollatsek et al., 1992; Van Orden, 1987; Van Orden et al., 1988).

It has to be noted that there is a possible objection against both suggested accounts, namely that resource depletion as well as inhibition should potentiate the relative slowness of lexical access to low frequency words. High task overlap should thus increase the word frequency effect, resulting in an overadditive interaction of word frequency and SOA, as spelled out by McCann et al. (2000) for the inhibition scenario and by Pashler and Johnston (1989) for the resource account.

This prediction clearly holds true when inhibition or resource sharing is assumed to be the only reason for dual-task slowing. However, we suggest an early interference caused by inhibition of word processing or by sharing of auditory processing resources, and a central interference causing a slack time for T2 decision and response selection processes which cannot proceed while central attention is dedicated to another task. The overproportional impairment of low frequency words might then well be absorbed into the waiting period, resulting in an additive or even an underadditive RT pattern.

Therefore, resource sharing as well as inhibition seem to be compatible with the behavioural results reported in the literature and found in the present experiment, and may account for the observed modest delay and amplitude reduction of the electrophysiological indicator of lexical access in conditions of high task overlap.

In sum, we combined the overlapping task paradigm with recording ERPs in order to investigate whether lexical access in visual word recognition is autonomous. The lexical decision task RTs showed an underadditive interaction of SOA and a difficulty manipulation of lexical access by means of word frequency, indicating lexical access to take place although central attention was dedicated to another task. However, the effect of word frequency on the ERP, used as electrophysiological indicator of lexical access and allowing for on-line assessment of lexical access and its modulation by task overlap, was moderately delayed and reduced in amplitude. This shows that, while not completely impeded without available central attention, lexical access was slowed and associated with less cognitive activity in conditions of high task overlap. Therefore, we conclude that lexical access in visual word recognition does not seem to occur completely autonomously.

4. Experimental procedures

4.1. *Participants*

Twenty four native Spanish speakers (17 women) with a mean age of 20.8 (range 18–33), took part in the experiment. According to a handedness questionnaire (Oldfield, 1971), all of them were right-handed. Their auditory acuity was sufficient to yield high pitch discrimination performance in a single-task practice block conducted prior to the experiment proper. Participants were students from introductory psychology courses at the University of La Laguna and received course credit for their participation.

4.2. *Stimuli and apparatus*

LDT stimuli were 240 disyllabic Spanish words, selected from the LEXESP Spanish data base (Sebastián-Gallés et al., 2000), and 240 pseudowords consisting of two legal Spanish syllables. All stimuli were of four or five letters, and the structure of the first syllable was always a consonant followed by a vowel (CV structure). All pseudowords were pronounceable. All words were content words (nouns, verbs or adjectives) presented in singular form. No inflected forms were included. Half of the words were of high word frequency according to LEXESP ($M=82$ per one million words; $SD=115$; range=9–676) and the other half were of low frequency ($M=3.4$; $SD=1.9$; range=0.3–8). Orthographic neighbourhood size, defined as the number of words that can be created by changing one letter of the stimulus item, preserving letter positions, was matched across conditions. The stimuli were presented in light grey lower case letters in the middle of the dark grey screen, positioned at eye level 80–90 cm in front of the participants. Stimuli for the additional task were two sinusoidal tones of 1000 and 800 Hz and 60 ms duration, presented via two loudspeakers located to the right and left of the screen. The keys for the manual responses were to be operated with the index fingers. Foot responses were recorded with two keys embedded into a wooden footrest, which were to be pressed with the big toes, shoes being taken off. Stimulus presentation and recording of responses was controlled by Presentation software (Neurobehavioural Systems, Inc.).

4.3. *Procedure*

A trial started with a fixation point presented in the middle of the screen. After an interval of 2 s one of the tones was presented. Participants were to indicate as fast and as accurately as possible with their left or right foot whether the tone was of high or low pitch. The LDT stimuli were presented 100 or 700 ms (for high and low task overlap, respectively) after tone onset. Participants were to indicate whether the letter string was a word or not with their left or right index finger, respectively. Participants were instructed to perform the LDT as fast and as accurately as they could, but to give priority to the pitch discrimination task. The letter string remained on the screen until both responses had been emitted or until 2500 ms had elapsed. The next experimental trial started immediately afterwards or after written error feedback, presented for 250 ms on the screen. Error feedback was given if at least one of the key presses was incorrect or missing or if the LDT response had been emitted before the response to the tone. Participants were seated in a dimly lit, sound-attenuated chamber. There were four practice blocks of 48 trials each to familiarize participants with the task requirements. Pitch discrimination task and LDT were first practiced in single-task blocks, and then in combination in two dual-task blocks. For practice trials, different letter strings were used than in the experiment proper. The experiment comprised a total of 480 trials, subdivided into eight blocks of sixty trials each. The blocks were separated by short breaks. All possible condition combinations of tone pitch, SOA, lexicality and word frequency were of equal probability, and each letter string appeared only once. Trials appeared in a different random order for each participant. The assignments of tone pitch to response foot and of lexicality to response hand were counterbalanced across participants.

4.4. *EEG recording*

The EEG was recorded continuously with a 250 Hz sampling rate from 64 tin electrodes mounted in an electro-cap (ECI Inc.) and referred to a linked earlobe reference. The horizontal and vertical electrooculograms (EOG) were recorded bipolarly from the external canthi and from above and below the midpoint of both eyes. Bandpass was set to 0.032–70 Hz, and a 50 Hz notch filter was applied.

Offline, the continuous EEG was segmented into epochs of 1600 ms, starting 800 ms before letter string onset. After applying a 30 Hz low pass filter, eye blink artifacts were corrected according to Gratton et al. (1983). Trials with activity in any cephalic channel that exceeded 75 μV and trials with incorrect or missing responses were discarded. Before generating averages for each subject, electrode and experimental condition, the epochs were referred to a baseline starting 100 ms prior to the LDT stimuli.

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Appendix: Influence of task overlap on lexicality effects

Because the LDT used as T2 requires participants to decide whether a letter string is a word or not, lexicality had to be manipulated in the stimulus set as well, allowing for an additional analysis of lexicality effects and their modulation by task overlap. This is interesting for two reasons: First, similar to ERP word frequency effects, ERP lexicality effects have also been interpreted as electrophysiological indicators of lexical access (e.g. Braun et al., 2006, Hutzler et al., 2004), thus providing a means of verifying the conclusions derived from the word frequency effects. As expected, ERPs to pseudowords were more negative than those to words, $F=5.196$, $p<.05$, in a segment from 350–650 ms poststimulus. The peak of the lexicality effect was determined in pseudoword — word difference waves in the left anterior cluster, where the effect was greatest, following the scheme described for the word frequency effect, and analyzed accordingly. ANOVAS revealed no significant decrease in amplitude with decreasing SOA, $Fcorr<1$, with peak amplitude means of −1.57 for long and −1.18 μV for short SOA. However, the peak latency of the difference wave was significantly delayed in conditions of high task overlap, $Fcorr\,(23, 1)=2.9$, $p=.05$ (one-tailed), with mean peak latencies of 452 and 556 ms for long and short SOA, respectively.

As for the ERP word frequency effect, this delay of 104 ms was modest in size compared with the 385 ms delay in RT2s, thus providing converging evidence for lexical access being slowed but not blocked in conditions of high task overlap.

The second reason for analyzing lexicality effects in dual-task settings relates to the nature of lexicality effects in RT. Following Coltheart et al. (1977), the typical finding of slower responses to pseudowords than to words is commonly attributed to a deadline process underlying nonword decisions. Letter strings are held to be classified as nonwords when a certain amount of time has elapsed without recognizing them as words. This account suggests a postlexical locus of the effect at the decision stage, and predicts additive effects of lexicality and SOA, as pointed out by McCann et al. (2000). These authors found additivity in their first experiment, and a slight trend towards underadditivity in their second experiment, which makes it difficult to draw clear conclusions. Here, we replicated the typical finding of shorter RTs to words than to pseudowords, $F(1, 23)=11.41$, $p<.01$. Importantly, however, there was no nteraction of lexicality and SOA, $F<1$, with mean lexicality effects of 29 ms for long SOAs and 25 ms for short SOAs. Hence, the effect was not absorbed into cognitive slack, but combined additively with SOA, consistent with the predictions derived from the decision stage account of RT lexicality effects.

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