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Neural indices of spoken word processing in background multi-talker babble

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Abstract

Objective: To evaluate the impact of multi-talker babble on cortical event-related potentials (ERPs), specifically the N400, in a spoken semantic priming paradigm. *Design:* Participants listened in quiet and with background babble to word triplets, evaluating whether the third word was related to the preceding words. A temporo-spatial principal component analysis was conducted on ERPs to the first and second words (S1 and S2), processed without an overt behavioral response. One factor corresponded to the N400 and revealed greater processing negativity for unrelated as compared to related S2s in quiet and in babble. *Study Sample:* Twelve young adults with normal hearing. *Results:* Background babble had no significant impact on the N400 in the posterior region but increased neural processing negativity at anterior and central regions during the same timeframe. This differential processing negativity in babble occurred in response to S2 but not S1. Furthermore, background babble impacted processing negativity for related S2s more than unrelated S2s. *Conclusions:* Results suggest that speech processing in a modestly degraded listening environment alters neural activity associated with auditory working memory, attention, and semantic processing in anterior and central scalp regions.

Sumario

Objetivo: Evaluar el impacto del balbuceo de múltiples hablantes en los potenciales corticales relacionados con eventos (ERP), específicamente el N400, en un paradigma de habla de base semántica. *Diseño:* Los participantes escucharon en silencio y con balbuceo de fondo, tripletas de palabras, para evaluar si la tercera palabra estaba relacionada con las palabras precedentes. Se realizó el análisis témporo-espacial del componente principal sobre los ERPs, en las palabras primera y segunda (S1 y S2), procesadas sin una respuesta conductual manifiesta. Un factor correspondió al N400 y reveló una negatividad de procesamiento para la no relacionada, en comparación con la S2 relacionada, tanto en silencio como con balbuceo. *Muestra de Estudio:* Doce adultos jóvenes con audición normal. *Resultados:* El balbuceo de fondo no tiene un impacto significativo en el N400 en la región posterior pero aumentó la negatividad de procesamiento en las regiones anterior y central durante el mismo marco temporal. Esta diferente negatividad diferencial de procesamiento con balbuceo, ocurrió en respuesta a S2 pero no a S1. Más aún, el balbuceo de fondo impactó la negatividad de procesamiento para las S2 relacionadas, más que para las S2 no relacionadas. *Conclusiones:* Los resultados sugieren que el procesamiento del lenguaje en un ambiente de escucha modestamente degradado, altera la actividad neural asociada con la memoria auditiva activa, la atención y el procesamiento semántico en las regiones anterior y central de la cabeza.

Key Words: Event-related potentials; Semantic processing; Speech processing in noise; Monolinguals

It is well documented that a degraded listening environment (e.g. background noise, babble, masking) affects the ability to understand speech. Indeed, it is likely that the difficulty extracting information from the speech signal in such conditions stems from multiple stages within the peripheral and central processing network (Nabelek & Pickett, 1974; Bronkhorst & Plomp, 1989; Helfer & Wilber, 1990; Crandall & Smaldino, 2002; Musiek & Chermak, 2007; Helfer & Vargo, 2009).

Processing spoken language in any listening environment requires that an individual rapidly integrate an acoustic signal with higher cognitive processes (i.e. attention, memory, lexical storage, context, semantic and syntactic knowledge) to derive meaning (e.g. Kent, 1992; Mehta et al, 2009). Even though behavioral measures can assess the ability of an individual to respond to an auditory task, they often do not provide detail regarding when or where in the process a breakdown occurs. For example, is poor performance due to reduced audibility, poor temporal processing of acoustic features, difficulty segregating competing signals, poor semantic processing capabilities, attentional overload, or something else (i.e. Martin et al, 1999; Hannemann et al, 2007; Mattys et al, 2009)?

Although spoken words and sentences are believed to be processed ‘on-line’ as they occur over time, comprehension is not linear or simple. The neural network involved in comprehension interweaves acoustic, phonologic, semantic, and syntactic cues provided by the integration of incoming sensory signals and top-down contributions (i.e. Naätanen, 1992; Stapells, 2002). Much research has been dedicated to investigating neural and cortical correlates of speech processing, employing techniques that permit a temporal and/or spatial

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Abbreviations

ERP	Event-related potential
PMN	Phonological mapping negativity
SFN	Sustained frontal negativity
TSPCA	Temporo-spatial principal components analysis

glimpse at cortical pathways and regions while processing unfolds from detection to comprehension (Scott et al, 2004; Wong et al, 2007; Martin et al, 2008; Mehta et al, 2009). The impact of noise on early cortical components such as the P1, N1, P2, MMN and P3a, primarily linked with pre-attentive stages (Martin et al, 1997; Shtyrov et al, 1998; Martin et al, 1999; Kozou et al, 2005; Martin & Stapells, 2005), has been well established while listening to speech syllables, and is generally characterized as reduced amplitudes and/or delayed latencies at vertex electrode sites that are typical to early auditory perception.

Receptive spoken language, however, entails much more than acoustic processing of information. In a classic ERP study, Kutas and Hillyard (1980) identified a processing negativity at approximately 300 to 600 ms post target onset in response to semantic relatedness. With the final word in written sentences as the target, processing negativity was observed to significantly increase in response to semantic *un*relatedness. For example, the final word in a sentence such as 'I like my coffee with cream and *socks*' evoked greater processing negativity than the word 'sugar' in 'I like my coffee with cream and *sugar*'. Generally referred to as the N400, it is well accepted that this ERP component represents comprehension of a potentially meaningful event (Kutas & Federmeier, 2000; McNamara, 2005). The N400 is recorded maximally at posterior electrodes (e.g. centro-parietal region) with a symmetric, more anterior distribution for auditory signals (e.g. McCallum et al, 1984; Bentin et al, 1993; Anderson & Holcomb, 1995; Kutas & Federmeier, 2000). It is interesting to note that studies investigating neurophysiological responses to semantic *and* phonological factors in the auditory modality have noted an anterior component that precedes the N400 (phonological mapping negativity or PMN), presumably contributing to the more frontal distribution of the auditory N400 (Connolly & Phillips, 1994; Steinhauer & Connolly, 2008).

The limited research regarding the impact of acoustic degradation on the auditory N400 component and N400 effect (i.e. the difference in negativity in response to unrelated compared to related targets) reveals conflicting results. Three studies, each employing sentential paradigms, investigated the auditory N400 as a function of listening condition (Aydelott et al, 2006; Connolly et al, 1992; Daltrozzo et al, 2005). Findings vary from a significant reduction (Aydelott et al, 2006) to a significant enhancement (Daltrozzo et al, 2005) to essentially no change (Connolly et al, 1992) in the N400 effect in adverse listening conditions. Methodological differences may contribute to the contradictory results, however it is clear that this area of research deserves more study. Although focused primarily on the impact of phonologically-matched masking on the phonology-related PMN component, Connolly et al, also measured the N400 to final words in sentences of high contextual constraint (*The pilot flew the* _____) versus low contextual constraint (*The pilot saw* _______). The N400 effect, that is, greater N400 negativity for low constraint versus high constraint sentences, was sustained in both listening conditions. Interestingly data tables in the paper revealed decreased negativity for both target types in noise, however the shift was not significant and the relationship between target word amplitudes did not change. In contrast, Daltrazzo et al, reported a significant increase in the N400 effect for terminal words in sentences presented with low pass filtered noise. The change was attributed to a strong positive shift in N400 amplitude for congruent words, especially at parietal electrodes, which increased the difference between the N400 elicited by congruent and incongruent sentences. The authors concluded that listening in noise impacted both the automaticity and facilitation of semantic processing for congruent words, resulting in greater dependence on context in the degraded listening condition. Yet another outcome was reported by Aydelott et al, who approached the question of how degraded listening conditions impact semantic processing from a different angle. The authors measured the N400 to mid-sentence congruent/incongruent target words when the surrounding context was either acoustically intact or degraded. Differing from both the Connolly et al and Daltrazzo et al studies, results revealed an attenuated N400 effect driven by a shallower N400 for incongruent words surrounded by degraded context. The authors suggested that the acoustic degradation reduced the availability of semantic information thereby influencing the neural response to word meaning. They also acknowledged, however, that the results should be interpreted with caution since an obvious overlap of the N400 with a P3 component could have been elicited by the perceptual change between the degraded context words and the acoustically intact target.

Although reported findings regarding the impact of background noise on higher levels of auditory processing (i.e. N400 and semantics) are equivocal and limited, particularly given variations in the methodology, it is important to note that in each of the three mentioned studies a N400 was evoked and recorded in a degraded listening environment. This suggests that the listener was able to 'fill-in' uncertainties in the speech signal with cues from available acoustic information in combination with recognizable sentential context. Indeed, bottom-up and top-down cues contribute to the use of redundancy of the speech signal and together facilitate comprehension when the signal is less than perfect.

As convincingly demonstrated by Mehta et al (2009), the allocation of cognitive resources (such as working memory and attention) contributes greatly to the process of word recognition. Interestingly, like the N400, the allocation of attention is expressed in a processing negativity between 300–600 ms post word onset (Naätanen, 1990), but is spatially distributed over anterior regions, oriented slightly to the left of midline (Mehta et al). This sustained frontal processing negativity is greatly enhanced by increased performance effort or attentional processing. Chao and colleagues (Chao & Knight, 1996, 1998; Chao et al, 1995) conducted a series of ERP studies examining the role of the prefrontal cortex on auditory working memory. An auditory recognition memory task administered to healthy, young adults elicited a sustained frontal negativity (SFN) between 375–600 ms that was significantly enhanced when an auditory distracter was added. Furthermore, the SFN was attenuated during the easiest tasks and completely abolished in the absence of attention (Chao et al).

As described in the previous paragraphs, it is understood that the processing negativity between 300 and 600 ms encompasses several cognitive processes, including: (1) the allocation of attention and working memory; and (2) semantic processing. These temporally overlapping components can be distinguished based on their spatial distribution. In the remainder of this document we will refer to the processing negativity over the anterior region as the sustained frontal negativity (SFN), and to the processing negativity over the posterior (parietal) regions as the N400. Because the N400 typically also occurs at the central electrode sites, there is spatial overlap between the N400 and the sustained frontal negativity. Indeed, the topographic distribution of the sustained frontal negativity has been shown to extend to the central regions (e.g. Chao & Knight, 1997). Hence, we will refer to the negativity evoked at the left and right central spatial factors in general terms (i.e. as the processing negativity), with the understanding that the N400 and SFN may be simultaneously encompassed in this negativity.

The primary goal of this study was to investigate the impact of a common background noise, multi-talker babble, on the processing negativity known as the N400, a neural correlate of the ERP waveform associated with higher level cognitive and semantic processing. To this end, participants performed a semantic priming task under quiet and adverse listening conditions. Semantic priming in the behavioral domain refers to an improvement in perceptual performance (i.e. facilitation) when a meaningful stimulus (written or spoken word, picture, environmental noise) is preceded by a semantically related or congruous stimulus (Neely, 1977, 1991; Kutas & Federmeier, 2000; McNamara, 2005). The initial stimulus is referred to in the literature as the 'prime' and the subsequent stimulus is referred to as the 'target'. Word recognition is faster when a target is facilitated by a preceding stimulus that is related or congruous (i.e. dog–cat; pen–write) compared to when it is inhibited by a preceding stimulus that is unrelated or incongruous (i.e. shoe–cat; knee–write). This phenomenon has been demonstrated behaviorally in the visual and auditory domains for word pairs, strings of words, and words within sentences.

As stated earlier, the 'priming effect', or improvement in perceptual and/or cognitive processing in conditions of semantic/contextual congruency or relatedness, has also been demonstrated in the N400 component of the ERP waveform (e.g. Kutas & Hillyard, 1980; Holcomb & Neville, 1990; Hagoort & Brown, 2000). The priming effect in the N400 is characterized by shallower negativity in response to related targets relative to unrelated targets. Even though the N400 has been examined extensively in the study of semantic processing, an accurate measure of N400 can be difficult to separate from concomitant components (i.e. P3) that are elicited by influences other than semantic relatedness, such as physical changes in the stimulus and/or overt decision making in response to the target stimulus (e.g. Aydelott et al, 2006; Bentin et al, 1993; Holcomb, 1993). A P3 elicited concomitant with the N400 is likely to impact the latency and amplitude of the actual N400. Yet a benefit of applying ERPs to the study of semantic processing is that an overt response is not necessary to elicit neural activity. Careful design of a priming paradigm, specifically one that maintains a consistent speaker and listening condition within a single trial and that maximizes semantic processing without requiring that an overt behavioral response occur simultaneously with the target word, can facilitate a direct comparison of the 'primed' waveform and 'unprimed' waveform without P3 interference (Kutas & Hillyard, 1989; Deacon et al, 1995).

Deacon et al (1995) employed a visual word priming paradigm that maximized semantic processing and delayed an overt response to well beyond the epoch of the target word. The goal was to evaluate the sensitivity of N400 to semantic priming without interference from a P3. Participants silently read two semantically related or unrelated words followed by a third word and were instructed to decide if the third word was semantically related to one or both of the preceding words. The second word (S2) remained the target word of interest. The overt semantic judgment to the probe word (S3) removed a concomitant P3 from interfering with the N400 to the target. It also increased the level of attention to word meaning throughout the task, maximizing N400 amplitude to both primed and unprimed words.

This word level priming paradigm is well suited to evaluating semantic priming effects for auditory stimuli in that it creates an opportunity to examine the neural correlates of semantic processing (i.e. N400) at the word level during attentive listening without requiring an overt behavioral response (Mehta, 2008). We suggest that this is reflective of much of everyday listening. Individuals listen and process individual words in order to comprehend a larger message without overtly acknowledging that each word was understood. Full sentences arguably contribute more contextual cues to the attachment of meaning to a final word; however, priming paradigms that utilize word pairs or triplets remove the influence of full sentential context and permit a more focused examination of semantic processing at the word level. Similar to Mehta (2008) who adapted Deacon's paradigm in the auditory domain to evaluate the impact of age on semantic priming, we used spoken instead of written word triplets to examine the neural indices associated with word processing in the presence of background babble. Specifically, we sought to examine the processing negativity of the auditory ERP in young adults as a function of listening condition and semantic relatedness.

In the current study, the presence of background babble while concentrating on the relationship between spoken words was expected to impact access to the desired acoustic signal, thereby taxing attentional and cognitive resources needed during semantic processing. Consequently, we expected the processing negativity at anterior electrode sites (SFN) to be enhanced when listening in background babble as compared to listening in quiet. Furthermore, we expected the degraded listening condition to impact the N400 of target words regardless of their semantic relatedness. Based on previous findings, however, we predicted two possible outcomes regarding the impact of background babble on the N400 effect (that is, the impact on related targets versus unrelated targets): (1) If data followed the trend reported by Connolly et al (1992) we predicted that the processing negativity of the N400 would essentially be unaffected or minimally attenuated in babble for both target types (related and unrelated S2s) and therefore have little impact on the N400 effect; or (2) if data followed that reported by Daltrozzo et al (2005) we predicted that background babble would attenuate ERPS to related target words more than unrelated target words, thereby accentuating the N400 effect.

Materials and Methods

Participants

Twelve monolingual female English speakers were recruited by word of mouth. We limited the study sample to female participants because of known gender effects on the N400 (Daltrozzo et al, 2007). All participants were current or recent students of an American college or university and provided informed consent in accordance with the Montclair State University Institutional Review Board.

All participants had normal hearing bilaterally (≤20 dB HL at octave frequencies from 250–8000 Hz) and normal middle-ear function. They were right handed (Annett, 1972) and had no history of neurological disorders, auditory processing disorders, and/or language disorders. To verify the ability to recognize monosyllabic words in the same noise condition that was used during the main experiment, each participant also completed a word recognition test (NU6 List 1, 50 words) in sound field with +9 dB SNR using multi-talker babble. All participants obtained word recognition scores greater than 90% correct at +9 dB SNR.

Stimuli

Word triplets were generated in order to employ a classic priming paradigm in the auditory modality in which the participant indicated if the probe word (S3) was semantically related to the prime (S1) and/or the target (S2) word(s). Table 1 lists stimulus types and the stimulus abbreviations used for the remainder of this document.

The word triplets were created using a Latin square design adapted from McNamara (2005) (Table 2). Initially, a total of 184 *primed* (henceforth referred to as *related*) pairs of monosyllabic English words were selected from the Word Association, Rhyme and Word Fragment Norms (Nelson et al, 1998). 'Relatedness' was defined in this case as one word being associated in any way (categorically or associatively) with another word, i.e. couch–sofa; broom–sweep. For more information regarding the predictive relationship of free association norms to priming and cued recall, see Nelson et al (1998). The *related* word pairs were divided into four lists (A, B, C, D) of 46 pairs such that the lists were balanced for forward prime-to-target (S1–S2) relatedness strength, prime (S1) frequency, and target (S2) frequency (Table 3). The target words (S2) were subsequently rearranged within each list so that *unprimed* (henceforth referred to as *unrelated*) S1–S2 word pairs were generated, creating lists A', B', C', D'. Finally, a third word was added to each word pair and served as the probe word that prompted participants to make a semantic decision well after the target word had been processed. Because we did not intend to examine the ERPs to S3 we did not control S3 for word frequency or relatedness strength. Note that the complete list of word triplets can be requested by contacting the corresponding author.

All prime (S1) and target (S2) words were monosyllabic. All probe (S3) words were mono or bi-syllabic. All words were digitally recorded in a double walled sound attenuated room by a female monolingual English speaker of Standard American English at a sampling rate of 16000 Hz with 16-bit amplitude resolution using Cool Edit Pro. Words were edited and equated for average RMS amplitude and presented through a single loudspeaker at an average intensity of 70 dBA.

Table 1. Description of word triplet stimuli and corresponding abbreviations.

Stimulus abbreviation	*Stimulus type*
S1	Prime word • First word of a word triplet • Monosyllabic • Active listening, but no overt response required
S2R	Related target word • Second word in a word triplet • Monosyllabic • Related to preceding prime word • Active listening, but no overt response required
S2UR	Unrelated target word • Second word in a word triplet • Monosyllabic • Unrelated to preceding prime word • Active listening, but no overt response required
S3	Probe word • Third word in a word triplet • Mono- or bi-syllabic • Related to S1 and/or S2 in 50% of the word triplets • Requires overt lexical decision: Related or unrelated to preceding S1 and/or S2?

Presentation of word triplets

Word triplets were presented in one of four 368-triplet sequences. Each sequence consisted of two runs of 184 triplets. Within each run, the first word (S1) of each triplet was always unrelated to the third word (S3) of the preceding triplet. S3 was related to S1 and/or S2 in 50% of the trials and unrelated to either in 50% of the trials. The second word (S2) was related to S1 in 50% of the trials and unrelated in the other 50%. Finally, 50% of all triplets were presented in quiet and 50% of all triplets were presented with background babble. There were no word repetitions within a run. Sample word triplets are displayed in Table 4.

For each sequence, Run 2 contained the same words heard in Run 1, but the semantic relationship between S1 and S2 was reversed (Table 2). It is important to note that the words were presented in the same listening condition for both runs (Table 2).

To limit potential fatigue and order effects, the quiet and babble conditions within each run were randomly divided such that six blocks of 15–16 triplets were presented in quiet, and six blocks of 15–16 triplets were presented in babble. Note: Dividing 184 triplets into twelve blocks resulted in eight blocks of 15 triplets and four blocks of 16 triplets. The blocks were carefully counterbalanced across subjects. The same listening condition never occurred more than twice consecutively.

Background noise

Background babble was used for the noise condition during the semantic listening task. Background babble consisted of 20 talkers and simulated a listening condition common to a cafeteria, noisy classroom, or crowded public space. To ensure running babble throughout the duration of each degraded listening condition, a 20-person babble previously recorded by AUDiTEC was concatenated digitally onto CDs and sent from two CD players (SONY HDMI) to two power amplifiers (Crown XLS202) before being presented from four loudspeakers (Realistic Minimus). To ascertain that the signal-to-noise ratio (SNR) used during ERP recordings represented a condition in which speech was challenging but not impossible to hear, percent correct scores for word recognition of all prime and target words (S1 and S2) across five signal-to-noise ratios (-3, 0, $+3$, $+6$, $+9$) were obtained for four monolingual individuals; ERPs were not recorded. A signal-to-noise ratio of $+9$ dB SNR was selected for use during ERP recording because mean percent correct scores were greater than 95% (Figure 1), enabling analysis of neural responses to speech that remained recognizable in the presence of background babble.

Testing environment

ERP testing was conducted in soundfield in a single walled, sound-attenuated, and electrically shielded booth. Participants were seated in a chair centered in the booth. The word triplets were presented from a loudspeaker located directly in front of the participant at ear level and a distance of 1.4 metres. During the babble condition multi-talker babble was presented from four loudspeakers located at $\pm 45^\circ$ and $\pm 135^\circ$ of center/midline (also at ear level and a distance of 1.4 metres). A visual prompt (i.e. '?') occurring simultaneous to S3 was projected by LCD projector through the booth window onto the booth wall directly behind the front speaker at eye height; the prompt alerted participants to make a button-push response. A response pad marked for consistent placement of the dominant index finger was held in the participant's lap on a lapboard.

Table 2. Development of word stimuli: Four sequences comprised of 368 word triplets each.

	Sequence 1		*Sequence 2*		*Sequence 3*		*Sequence 4*	
Run 184 triplets/run	*Quiet*	*Babble*	*Quiet*	*Babble*	*Quiet*	*Babble*	*Quiet*	*Babble*
Run 1								
S2R	A	B	B	D	D	C	C	A
S2UR	C’	D’	A’	C’	B’	A’	D’	B’
Run 2								
S2R	C	D	A	C	B	A	D	B
S2UR	A’	B’	B’	D’	D’	C’	C’	A’

Note: Test words (S1 and S2) were counterbalanced across four experimental conditions using a factorial combination of semantic relatedness and listening conditions. A, B, C, and D represent equal-sized subsets of *related* prime-target (S1-S2) pairs (46 pairs each). A’, B’, C’, and D’ are corresponding subsets of *unrelated* prime-target pairs, designated as S2UR, formed by re-pairing primes and targets. For this study, a third word (S3) was added to each pair such that it was randomly primed by S1 and/or S2 in ~50% of the trials in each run. Within each sequence, Run 2 contained the same words as Run 1 but prime-target (S1-S2) relationship was reversed. (Adapted from McNamara, 2005).

To ensure that participants maintained a forward-facing head position throughout testing, participants were instructed to look at a yellow circle on the front speaker during stimulus presentation.

Experimental paradigm

A modified version of an established semantic priming paradigm was utilized in which the participant listened to a series of three-word triplets (S1, S2, S3) and was instructed to decide by button push if the third word was related to one or both of the first two words (Deacon et al, 1995). The participant was not aware that the second word (S2), which was either related or unrelated to the first word (S1), was the target of interest. By attending to all three words but overtly responding only to S3, the decision process associated with the task was delayed, thereby reducing the overlap of the P3 ERP component with the N400 to the target word.

Based on pilot data obtained in our laboratory (unpublished) and on previous studies reported in the literature (Anderson & Holcomb, 1995; Kotz, 2001; Kotz & Elston-Guttler, 2004), an offset-to-onset inter-stimulus interval (ISI) of 600 ms was used between the prime (S1) and target (S2) words. Between S2 and S3 the ISI was 2100 ms. An interval of 3500 ms was used between S3 and the subsequent S1. The duration of a triplet from onset of S1 to onset of the subsequent S1 was approximately 8.25 seconds. Figure 2 represents the sequence and timing of a triplet constituting a single trial.

As mentioned previously, word triplets were presented in blocks of 15–16 trials. A short rest period was provided at the conclusion of each block. Visual prompts (‘REST’, ‘READY’) projected onto the wall directly behind the front speaker via LCD projector occurred between blocks of triplets. For example, ‘REST’ was displayed for five seconds at the conclusion of a block of triplets in quiet followed by ‘READY’ for ten seconds, alerting the participant that the next block of triplets (in quiet or in babble) was about to begin. Visual prompts (i.e. ‘?’) occurred at least 2100 ms after S2 presentation. S1 presentation always occurred 2000 ms after the offset of the ‘READY’ prompt. Therefore, the visual prompts were not expected to influence the auditory ERPs.

Each participant completed a total of 20 practice trials in quiet and in babble before the actual ERP recording began. No words from practice trials were utilized in actual recorded sessions. After the practice run, each participant listened to two runs of 184 triplets, for a total of 368 word triplets. After completing one run of 184 triplets, each participant was given a three to five minute break before commencing the second run.

Each run was 35 minutes in duration. Including the time required for application of the electrode cap, practice sessions, and a short break, total electrophysiological testing time was approximately two hours.

EEG recording and measurement

Electroencephalographic activity was recorded from forty-one Ag/AgCl electrodes embedded in an elastic electrode cap (Neurosoft) and placed according to a modified version of the International 10-20

Table 3. Relatedness and frequency-of-use characteristics of prime (S1) and target (S2) words across lists. (Nelson et al, 1998).

Word list	*S1-S2 Relatedness strength*	*S1 Prime frequency*	*S2 Target frequency*
List A	.605	67.6	120.7
List B	.606	70.7	107.1
List C	.604	68	109.8
List D	.601	72.2	118.6

Note: Mean relatedness strength and word frequency for each word list was calculated using data collected by Nelson et al (1998). Forward prime-to-target (S1-S2) relatedness strength represents the probability that S2 would be produced after hearing S1 (Nelson et al, 1998). Prime and target frequency represent a measure of printed word frequency in a sample of one million words (see Kucera & Francis, 1967).

Table 4. Sample word triplets from Sequence 1, Run 1 and Run 2.

Run	*S1 (Prime word)*	*S2 (Target word)*	*Relatedness condition*	*S3 (Probe word)*
Run 1	Mist	Beg	UR	Incline
	Scream	Yell	R	Scare
	Girl	Boy	R	Clock
	Inch	Fright	UR	Measure
Run 2	Plead	Beg	R	Point
	Tile	Yell	UR	Dark
	Low	Boy	UR	Cigar
	Scare	Fright	R	Fear

Note: If the target word was related (S2R) to the prime word in Run 1, it was unrelated (S2UR) in Run 2 but presented in the same listening condition (quiet or babble).

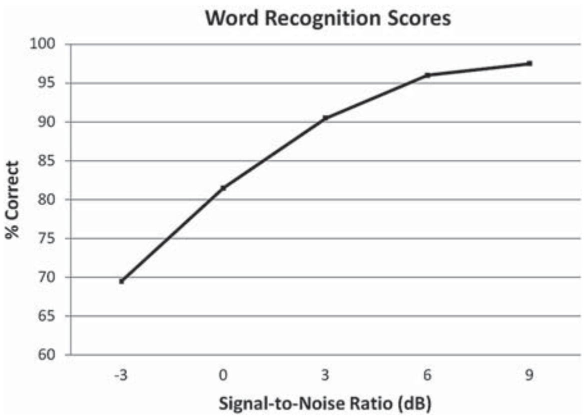

Figure 1. Word recognition as a function of signal-to-babble ratio for monolingual participants (n = 4). Stimuli were monosyllabic prime and target words used in the experimental paradigm for the present study.

system. Three additional electrodes were adhered, one to the bridge of the nose and two to transverse locations at the left eye (anterior and lateral), and served as a reference and eye blink monitors respectively. The ground electrode (APZ) was located 4 cm anterior to FZ on the midline. Electrode impedances measured less than 10 kOhms prior to ERP recording.

Electroencephalographic activity was recorded at a sampling rate of 1000 Hz and with analog filter settings from 0.15 to 70 Hz (slope −12 dB/octave) (SCAN 4.3, Compumedics Neuroscan, 2003). Sweep duration extended from −100 to 1500 ms relative to word onset. Offline signal averaging was carried out after artifact rejection (based on VEOG waveform exceeding ±50 μV), linear detrending procedures, low-pass (20 Hz) and band-stop (8–13 Hz) digital filtering with a filter slope of −48 dB/octave, and baseline correction procedures (based on the first 100 data points). Averaged ERPs were based on a minimum of 80 sweeps per stimulus type (S1 quiet, S1 babble; S2 quiet related, S2 quiet unrelated, S2 babble related, S2 babble unrelated).

ERP data analysis

In the current study, temporo-spatial principal components analysis (TSPCA) was used to extract distinct components describing the variance contributions of temporally and spatially overlapping ERP components that are often difficult to distinguish with traditional ERP measures (Kayser et al, 2001). TSPCA, a two-step statistical procedure, can facilitate analysis of ERP components and has been shown to be an effective method of characterizing condition effects (Dien et al, 2005; Dien, 2010). Temporal PCA uses time points as variables and spatial PCA uses electrodes as variables, each extracting a limited number of factors that represent significant changes in variance across time and space. The factor scores initially obtained from temporal PCA are applied to spatial PCA in order to cross reference the timing of significant cortical events with topographical location(s) on the scalp. Together, the two analyses allow ERP components that may occupy similar time courses to be separated topographically. Furthermore, instead of arbitrarily selecting a single electrode to represent an experimental condition, TSPCA allows a condition to be statistically evaluated across a cluster of electrodes. This two-step procedure is particularly advantageous when ERP components are not sufficiently distinct in either domain by itself (i.e. P300 and N400) (Dien et al, 2005; Dien, 2010).

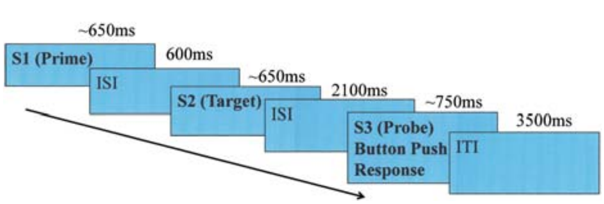

Figure 2. Sequence and timing of a single trial. One trial contained three spoken words, prime (S1), target (S2), and probe (S3), separated by inter-stimulus intervals (ISI) as specified. S3 was separated from the onset of the subsequent triplet by a 3500-ms inter-trial interval (ITI).

Results

Behavioral findings

For one subject, the behavioral data of the second run were not recorded due to technical difficulty. Therefore, we conducted the analyses of the behavioral findings on eleven subjects. All participants identified semantic relatedness of S3 to S1 and S2 correctly with >75% accuracy (accuracy scores >75% were obtained for Run 1 for the one subject with missing data for Run 2).

A repeated measures ANOVA on the percent correct scores indicated a significant main effect of listening condition (quiet vs. background babble), $F(1,10) = 6.386$, $p = .03$, of relatedness (unrelated to S1/S2, related to S1, related to S2), $F(2,20) = 8.182$, $p = .012$, and an interaction effect of listening condition by relatedness, $F(2,20) = 6.015$, $p = .012$. Subsequently, paired samples t-tests were conducted comparing listening in quiet and in background babble when S3 was: (1) unrelated to S1 and S2; (2) related to S1; and (3) related to S2. The effect of listening condition was significant when S3 was related to S1: $t = 3.017$, $df = 10$, $p = .013$. Correct identification of relatedness between S3 and S1 declined significantly when listening in background babble compared to quiet. Listening condition did not affect behavioral performance for the two other comparisons, $t = .568$, $df = 10$, $p = .583$ for S3 unrelated to S1/S2; $t = .673$, $df = 10$, $p = .516$ for S3 related to S2.

These findings point to an increase in task difficulty and attention/working memory demands during background babble as compared to quiet conditions when relatedness between S1 and S3 was to be identified.

Description of grand averaged waveforms

Grand averaged ERPs (n = 12) at individual electrodes are shown in response to S1, S2 R, and S2 UR as a function of listening condition and/or semantic relatedness (Figures 3–4). These electrodes were selected based on their high factor loadings for a specific spatial factor (SF) and are used for visual representation of TSPCA results. Electrode FPZ represents the anterior SF, electrode C3 the left central SF; electrode FC4 the right central SF, and electrode POZ the posterior SF.

Anterior SF

Over the anterior electrode sites (Figures 3a and 4a) time waveforms consisted of clear N1 and P2 components. In support of research studies examining the influence of background noise on CV processing (Martin et al, 1997; Shtyrov et al, 1998; Martin et al, 1999; Kozou et al, 2005; Martin & Stapells, 2005), the N1 and P2 activation in the anterior region appeared to be reduced and/or delayed

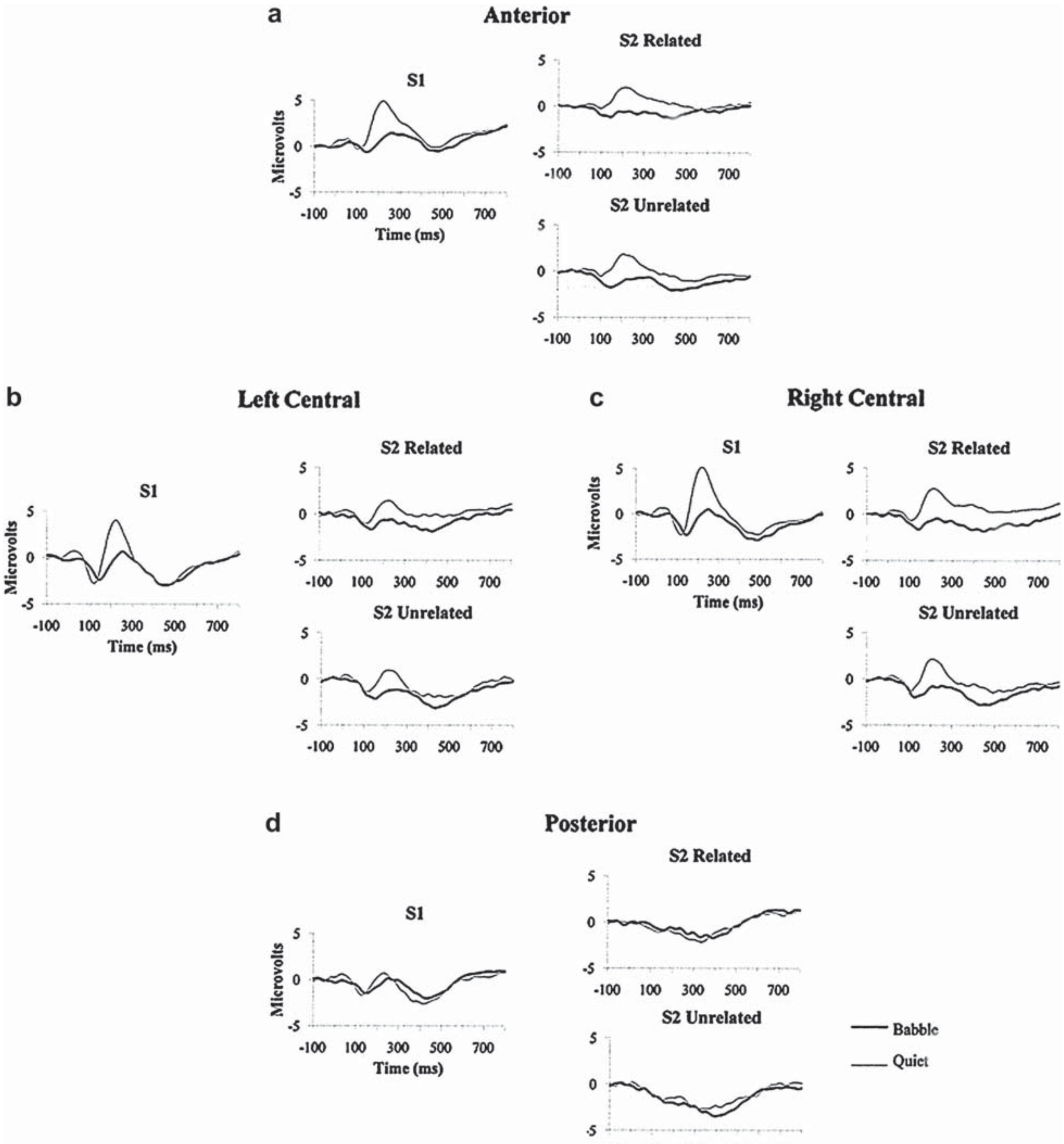

Figure 3. Grand averaged waveforms, comparing the effect of listening condition (quiet vs. babble) for S1, S2 R, and S2 UR (a) at electrode FPZ, representing the anterior spatial factor; (b) at electrode C3, representing the left central spatial factor; (c) at electrode FC4, representing the right central spatial factor; (d) at electrode POZ, representing the posterior spatial factor.

when words were presented with background babble as compared to in quiet for all three words (S1, S2 R, and S2 UR). In addition, a sustained frontal negativity (300–525 ms) was observed over the anterior electrode sites. In contrast to N1 and P2, the sustained frontal negativity observed over anterior electrode sites increased in the presence of background babble for S2 but not S1. In other words, processing of S2 words in background babble appeared to evoke greater sustained frontal negativity relative to the sustained frontal negativity observed to S2 words presented in quiet, whereas the sustained frontal negativity in response to S1 did not differ as a function of background sound environment.

Posterior SF

Grand averaged waveforms elicited at a posterior electrode site (POZ) in response to the prime (S1) and target words (S2R and S2 UR) are shown in Figures 3d and 4d. A negative post-stimulus deflection (300–525 ms) was prominent for the posterior spatial factor (SF1) and was identified as the N400. A clear N400 was evident

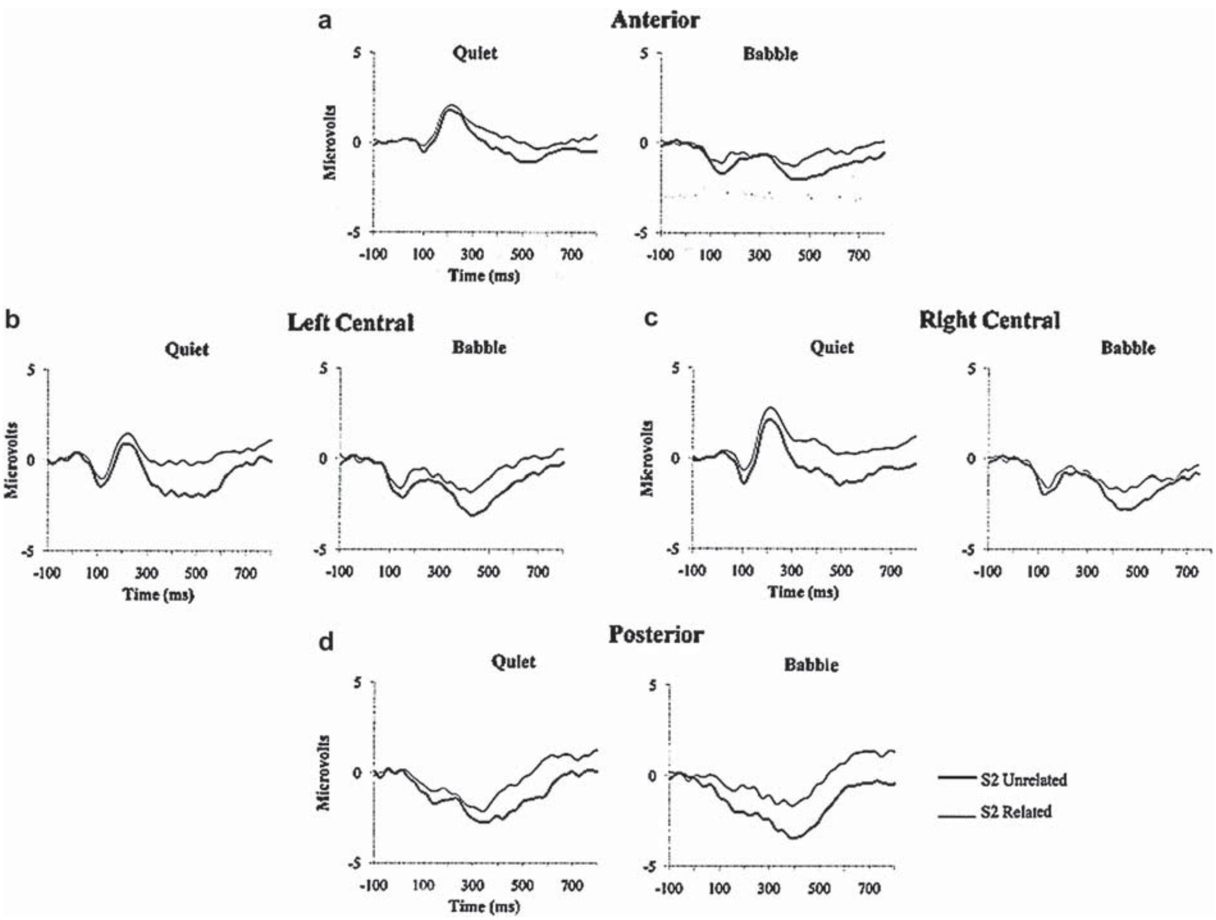

Figure 4. Grand averaged waveforms illustrating the effect of semantic relatedness in quiet and in babble (a) at electrode FPZ, representing the anterior spatial factor; (b) at electrode C3, representing the left central spatial factor; (c) at electrode FC4, representing the right central spatial factor; (d) at electrode POZ, representing the posterior spatial factor.

over posterior electrode sites for all three word types. Background babble did not appear to affect the N400 at the posterior electrode sites (Figure 3d). Reflecting the processing of word meaning and semantic relatedness, the N400 was characteristically more negative to unrelated targets as compared to related targets, regardless of listening condition (Figure 4d).

Left central SF

Grand averaged waveforms elicited at C3 represent the responses to S1, S2 R, and S2 UR for the left central spatial factor (Figures 3b and 4b). The N1 and P2 distinctions between listening in quiet and in background babble observed at the anterior SF are also present at the right central SF. While the processing negativity for S2 R is clearly more negative when listening in background babble than in quiet, the difference in the processing negativity as a function of listening condition is reduced for S2 UR and is not present for S1. The typical N400 effect (greater negativity for S2 UR than S2 R) is observed at the left central SF.

Right central SF

Grand averaged waveforms elicited at FC4 represent the responses to S1, S2 R, and S2 UR for the right central spatial factor (Figures 3c and 4c). Again, a clear difference in N1 and P2 activation is apparent for listening in quiet and in background babble. Clear differences are present in the processing negativity as a function of semantic relatedness and listening condition. Overall, unrelated targets evoked a greater processing negativity than related targets, and listening in background babble evoked a greater processing negativity than listening in quiet for the target words (S2 R and S2 UR) but not for the prime words (S1).

Temporo-spatial principal component analysis

Following data collection but prior to data processing, the sampling rate of the ERPs was reduced to 200 Hz to ensure a reasonable signal-to-noise ratio (a minimum of 10 observations for each variable) for the evaluation of the time course in a temporo-spatial principal component analysis (TSPCA).

As described earlier, the purpose of the temporo-spatial PCA is to extract distinct components describing the variance contributions of temporally and spatially overlapping ERP components that are difficult to distinguish with traditional ERP measures (Kayser et al, 2001). In the current study, a temporal PCA was followed by a spatial PCA. PCA analysis settings (Promax rotation, Kappa = 3, Kaiser normalization, extraction of an unlimited number of factors) were based on an established protocol that was shown to yield excellent results for ERP datasets (Dien et al, 2005).

The input to the temporal PCA consisted of 210 variables (210 time points between 0–1050 ms after word onset) × 2952 observations (12 participants × 41 electrodes × 6 stimulus types).

The extraction of an unlimited number of factors resulted in 210 temporal factors. The factor scores of these 210 temporal factors were subsequently used in the spatial PCA. The input to the spatial PCA consisted of 41 variables (electrodes) × 15 120 observations (12 participants × 210 temporal factors × 6 stimulus types).

In the temporal PCA seventeen temporal factors had an eigenvalue >1, explaining 99.13% of the total variance. The third temporal factor (between 300–525 ms, peak 395 ms) corresponded with the time interval of the N400 component to be explored in the current study, and is hereafter referred to as TF400. Figure 5 depicts the temporal factor loadings of this temporal factor.

In the spatial PCA six spatial factors had an eigenvalue >1, explaining 93.49% of the total variance. Four of the six spatial factors (SFs) yielded significant findings for TF400. Maps of the topographic distribution of these four spatial factors can be found in Figure 6 and illustrate that SF1 is located in the posterior region, SF2 in the anterior region, SF3 in the right central, and SF6 in the left central regions. Hereafter, SFs are labeled based on their topographic distributions.

Repeated measures ANOVAs.

To evaluate the impact of listening condition on the processing of semantic relatedness, separate repeated measures ANOVAs were conducted on the anterior, posterior, and left and right central spatial factor scores for TF400 in response to target words. Within-subject independent variables were listening condition (quiet, background babble) and relatedness (S2 R, S2 UR).

The N400 effect, i.e. observed as a greater processing negativity in response to unrelated compared to related target words (Figure 4b–d), was supported by a significant main effect of relatedness at the posterior SF, $F(1,11) = 9.670$, $p = .010$; left central SF, $F(1,11) = 5.979$, $p = .033$; and right central SF, $F(1,11) = 5.869$, $p = .034$. TF400 showed greater negativity for unrelated than related targets.

At left and right central SFs we also observed a main effect of listening condition, $F(1,11) = 6.901$, $p = .024$, and $F(1,11) = 22.175$, $p = .001$, respectively (Figure 3b–c). This main effect of listening condition extended to the anterior SF, $F(1,11) = 15.751$, $p = .002$

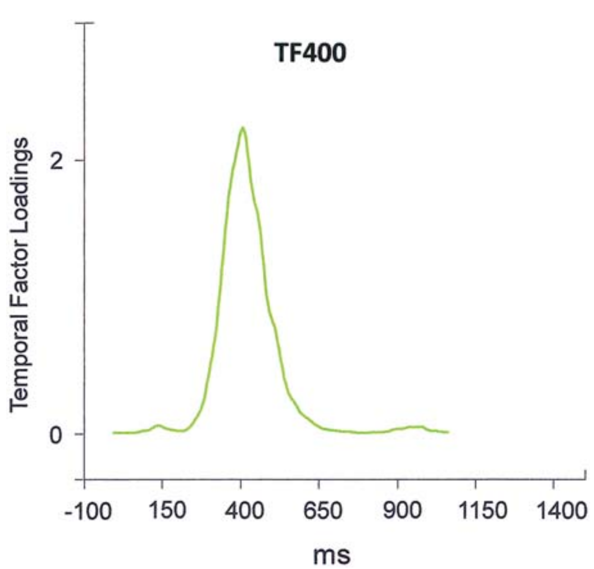

Figure 5. Temporal factor loadings for TF400.

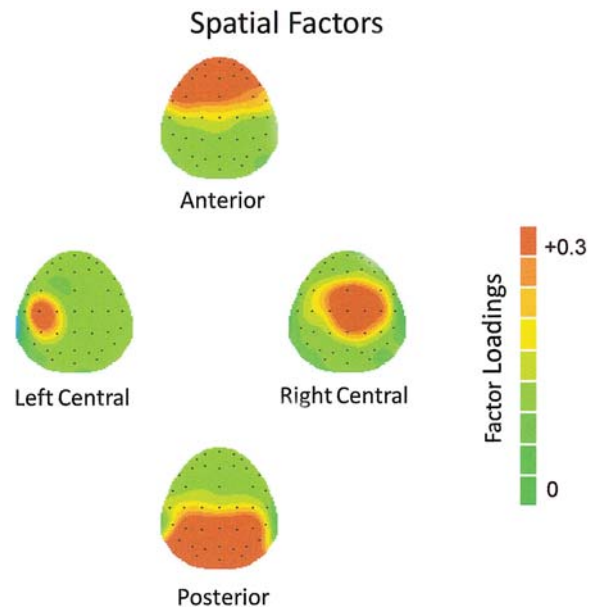

Figure 6. Spatial factor loadings for anterior, left central, right central, and posterior spatial factors.

(Figure 3a). To determine whether background babble impacted S2 R and S2 UR differently, a priori planned paired comparisons were conducted on the processing negativity in quiet versus babble for related and unrelated targets separately. The comparisons yielded significant differences between quiet and background babble for S2 R at anterior SF, $t = -2.697$, $df = 11$, $p = .021$; right central SF, $t = -4.076$, $df = 11$, $p = .002$; and left central SF, $t = -2.667$, $df = 11$, $p = .022$. In contrast, for S2 UR a significant difference between quiet and background babble was obtained for anterior SF, $t = -3.344$, $df = 11$, $p = .007$; and right central SF, $t = -2.787$, $df = 11$, $p = .018$; but *not* for left central SF, $t = -1.054$, $df = 11$, $p = .319$. As can be seen in Figure 3a–c, attenuation of the processing negativity was much greater for S2 R presented in quiet as compared to background babble for anterior, right central and left central SFs. Although a similar effect on the processing negativity was observed in the anterior and right central SFs for S2 UR, no significant differences were observed for S2 UR in the left central SF as a function of listening condition (Figure 3c). Hence, background babble had a more widespread impact on the processing negativity of S2 when the target word was preceded by a related prime.

To confirm that the listening condition was modulating S2 R to a greater extent than S2 in general, we examined statistical significance for the interaction effect of word by listening condition in separate repeated measures ANOVAs comparing S1 vs. S2 R and S1 vs. S2 UR. The listening condition by word interaction was significant for the repeated measures ANOVAs comparing S1 vs. S2 R at right central SF, $F(1,11) = 8.613$, $p = .014$, as well as left central SF, $F(1,11) = 5.841$, $p = .034$. At anterior SF, the interaction effect approached significance, $F(1,11) = 3.773$, $p = .078$. For the ANOVAs comparing S1 to S2 UR, the interaction effect was not significant at any spatial factor.

Of particular interest is the finding that a priori planned paired comparisons of S1 in quiet and in babble did not yield significant findings at anterior SF, $t = -.273$, $df = 11$, $p = .790$; right central SF, $t = -1.166$, $p = .288$; or left central SF $t = .034$, $p = .973$. Consequently, background babble appears to significantly affect the sustained frontal negativity (anterior SF)/processing negativity (central SFs) for the target words (S2) but not the prime (S1).

Finally, it is important to mention that background babble had no effect on the N400 in response to S1, S2 R, and S2 UR at the posterior electrode sites.

Discussion

This study investigated the impact of multi-talker babble on the neural indices of speech processing in a semantic priming paradigm for young adults with normal hearing. Participants were instructed to attend to each word in a series of word triplets (S1, S2, S3) that contained semantically related (R) or unrelated (UR) word pairs (S1–S2R and S1–S2UR, respectively), delaying their semantic decision until hearing S3 which was related to S1 and/or S2 for one-half of the trials. Replying to the third word permitted analysis of the processing negativity to S2 without interference from an overt-response-elicited P3 (Deacon et al, 1995). The aim of the present study was to compare the processing negativity for S1, S2R, and S2UR in quiet and in the presence of background babble, analyzing neural activation patterns elicited by semantic relatedness and listening condition.

In sum, our findings indicated that the processing negativity was greater to unrelated targets (S2 UR) than related targets (S2 R). This effect was observed more strongly over the central and posterior regions, and is consistent with the N400 effect reported in previous studies (e.g. Kutas & Federmeier, 2000). Second, the processing negativity was impacted by listening condition most noticeably over the anterior and central SFs. This coincides with the spatial distribution of the sustained frontal negativity. This sustained frontal negativity was more negative in response to S2 words presented in background babble as compared to in quiet. Interestingly, the sustained frontal negativity for S1 was not affected by listening condition. At central sites the processing negativity was not only more negative in response to S2 words in babble, but was also more widespread for related targets in babble than for unrelated targets in babble.

Effects of semantic relatedness on cortical activity have been well-documented in the literature and were evident in our results (for review see Kutas & Federmeier, 2000). As expected, an N400 effect to the target word (S2) was elicited during our active listening paradigm that did not require a concurrent overt response. Specifically, negativity at the central and posterior electrodes in a time interval associated with semantic processing (255–585 ms) was greater for unrelated as compared to related word pairs. This confirms previous findings that overt responses are not needed to evoke an N400 effect (Deacon et al, 1995; Mehta, 2008).

As background noise level increases, cortical components of detection (P1-N1-P2) are attenuated and/or delayed, but typically remain more robust than later, more endogenous components of cognitive processing, such as the P3 (Martin et al, 1997; Whiting et al, 1998). Although not the focus of this study, our results contribute to existing research on early, exogenous ERPs as evidenced by the dramatic attenuation of P2 in the presence of relatively modest background babble as observed in the grand averaged ERPs. In addition to supporting literature that differentiates P2 from its N1 neighbor (i.e. Fisher et al, 2000; O'Hare et al, 2008), an anonymous reviewer suggested that the attenuation of P2 in babble observed in our data warrants further study even if it may be influenced by the SFN. Indeed, it was suggested that combined with decreased phonology-related responses (PMN) reported by Connolly et al, (1992), we may be seeing evidence that increased attention and effort compensates for compromised earlier, bottom-up processes. However, our research paradigm was not designed to examine phonology-related changes in the ERP in background babble, and as such we cannot comment extensively on how changes in phonological perception in background babble may have impacted the P2 in our data. Nevertheless, beyond the P3 component, ERP research that addresses the impact of noise or babble on spoken word processing is limited. Therefore, our study not only contributes to existing research on early, exogenous ERPs but also examines later, endogenous components associated with higher levels of auditory and cognitive processing.

Our findings confirm that an N400 priming effect can be obtained in the ERP waveform when words are presented under adverse listening conditions. This is consistent with findings reported by Daltrozzo et al (2005) who actually observed a shallower N400 for related/congruent words in a moderate degree of noise as compared to quiet listening conditions while posterior negativity for unrelated/incongruent words remained essentially unchanged. In contrast, Aydelott et al (2006) reported that adverse listening conditions of sentential context significantly attenuated the N400 effect; that is, when the carrier sentence was low-pass filtered and the target word remained acoustically intact, the difference between the N400 amplitude for congruent versus incongruent target words was less than when the entire sentence was acoustically intact. As shown in the behavioral literature (Aydelott & Bates, 2004), it is conceivable that diverse types of acoustic degradation as well as methodological variations impact the N400 effect differently. In fact, Connolly et al (1992) reported that acoustic degradation did not impact the N400 effect to the point of obliteration. It is likely, however, that in the Aydelott et al (2006) study the P300 component evoked due to the differences in the physical properties between the target word and the carrier sentence decreased the N400 amplitude as well as the degree of priming.

The fact that the N400 effect can be evoked under adverse and quiet listening conditions suggests that the N400 priming effect is robust and also resistant to attentional and cognitive conditions. To be sure, albeit reduced in amplitude, the N400 priming effect has been shown in sleep (Brualla et al, 1998), during shallow processing tasks (Bentin et al, 1993), and under high working memory loads (D'Arcy et al, 2005).

Furthermore, our findings indicate that the presence of multi-talker babble impacts the processing negativity at anterior and central regions. While the processing negativity did not change at any electrode site in response to listening condition for S1, S2 processing was characterized by a greater sustained negativity in the anterior and central electrode sites when processed with babble as compared to in quiet. The topographic distribution of this negativity around 400 ms strongly resembles findings reported by Chao and colleagues (Chao & Knight, 1996, 1998; Chao et al, 1995) as well as Mehta et al, (2009). These authors suggested that the SFN reflects performance effort or attentional processing.

In the present study, the significant increase in anterior negativity during semantic word processing of S2 (around 400 ms), but *not* S1, in the noisy listening condition supports Chao et al's (1995) suggestion that the SFN reflects additional cognitive effort and/or attention during tasks of increased difficulty. Presumably, the combined cognitive effort required to listen in a challenging acoustic environment and hold S1 in working memory while processing S2 is reflected in anterior and central ERP responses for S2 as compared to S1. It is of note that our behavioral findings are in further support of this notion. The decline in performance accuracy for identification of semantic relatedness between S1 and S3 in background babble compared to quiet indicates that working memory was taxed. These behavioral results are not due to overall decline in performance in babble, because correct identification of semantic relatedness between S2 and S3 was not affected, nor was the identification of semantic unrelatedness. Given that communication takes place in the presence of many different types and intensities of noise, it is important to recognize that even a low level of babble can tax cognitive resources during an already complex process.

The fronto-central scalp distribution of the sustained frontal negativity suggests activity in the frontal brain areas (Chao & Knight, 1998). In a study that included patients with right or left frontal brain lesions, Chao and Knight revealed a focal reduction in the sustained frontal negativity in the scalp region over the damaged area during an auditory memory task. Evidence for the role of the prefrontal/frontal regions in speech processing in noise can be also found in recent functional neuroimaging studies. Wong et al (2008) investigated young adults' behavioral and hemodynamic response to single spoken word identification in three listening conditions: quiet, moderately loud noise (20 dB SNR), and loud noise (−5 dB SNR). Although the authors focused on significant noise-related changes in the superior temporal gyrus, both noise conditions also elicited additional activation in the prefrontal cortex when compared to cortical activity in quiet. As expected, cortical activity in regions impacted by background noise increased as a function of decreasing SNR. Of interest, however, is that significantly more brain activation was observed at the 20 dB SNR condition as compared to the quiet condition, despite no difference in behavioral performance. This was also observed in the present study: the babble condition (9 dB SNR) elicited a significantly amplified sustained frontal negativity for the target word (S2) during the time interval and in the topographic location typical of the SFN, while having little or no impact on behavioral responses (particularly when S2 and S1 were unrelated to S3, or when S2 and S3 were related). Together, these findings support our interpretation that the prefrontal/frontal cortex is activated during spoken word processing in babble and that we are likely observing an SFN in our ERP data.

Although background babble affected target words irrespective of their relatedness to the prime word, resulting in overall greater allocation of resources when listening to S2 in babble than in quiet, we observed that, with background babble, the processing negativity at the central sites was more widespread for related targets than unrelated targets. It is of note that the same words were presented in a related and unrelated semantic context. Hence, we excluded the possibility that there was a difference in the bottom-up processing of the target words, due to differential acoustic masking of related and unrelated targets. If the processing negativity observed at the central sites is influenced by two cognitive processes—allocation of attentional resources/working memory and semantic processing—these processes occur simultaneously in the ERP waveform and are not mutually exclusive. Indeed, a reduction, but not obliteration, of the N400 effect has been observed in normal adults when performing a task of semantic relatedness under high working memory load conditions (D'Arcy et al, 2005) or under task conditions requiring shallower levels of processing (Bentin et al, 1993). Similar to our findings, in both studies the reduction in the N400 effect was driven by the related target words. In D'Arcy et al, the N400 amplitude to the related targets was shallower in the low working memory condition than in the high working memory condition, while the N400 amplitude in response to unrelated targets did not differ between low and high working memory load conditions. In Bentin et al, the N400 amplitude to the related targets was shallower when semantic processing of the stimulus was induced (i.e. in a semantic memorization task) compared to when it was not induced (i.e. when counting non-words). Again, the N400 amplitude to the unrelated targets was not affected by task requirements. According to Bentin et al (1993, p.168) 'The amplitude of the N400 is apparently modulated by the degree of semantic elaboration that a word undergoes during semantic encoding'. In line with these findings, we suggest that the increased processing negativity to the related targets in background babble as compared to quiet in central and anterior regions indicates that (1) background babble increased the working memory load during semantic processing; and (2) related words underwent a lesser degree of semantic elaboration when background babble was present.

Results of the present study are of interest because we show that a modest amount of background babble (9 dB SNR) leads to changes in central processing beyond pure peripheral effects. Like many ERP studies, these results represent a small sample of individuals and we do not presume to generalize conclusions to the larger population. However, results add to a growing collection of scientific study regarding the impact of degraded listening environments on the neurological markers for speech. Our results may reflect a word level rendition of what we do during everyday listening: process incoming auditory cues, select a match from phonological and lexical storage, semantically process meaning, and hold multiple words in working memory while integrating the context of ongoing discourse, all in the presence of competing noise. This semantic paradigm with multi-talker babble reflects the challenges of real life listening more than single word identification or word recognition tasks with steady-state noise. However, future applications of this paradigm that allow the exploration of background babble with fewer speakers (i.e. four-speaker babble), differing signal-to-noise ratios and locations would contribute to our understanding of the impact of competing speech on word processing.

In conclusion, results of this study have shown that background babble affects neurophysiological responses linked to cognitive and semantic processing. Processing words in noisy environments may tax auditory working memory and attentional resources, thereby affecting how we make use of the contextual constraints in word comprehension.

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