

What does Dichotic Listening Reveal about the Processing of Stress Typicality?

Joanne Arciuli¹ and Louisa M. Slowiaczek²

¹Department of Psychology
Charles Sturt University,
Australia
jarciuli@csu.edu.au

²Department of Psychology
Bowdoin College,
USA
lslowiac@bowdoin.edu

Abstract

Despite its presence in all natural languages, importance for intelligibility, pivotal role during language acquisition and significance as a marker of language dysfunction, prosodic processing has been largely neglected in cognitive science. Here we examined hemispheric specialisation for linguistic word-level prosody, in particular, stress typicality, using dichotic listening. In Experiment 1 participants named targets and in Experiment 2 participants classified targets as being either nouns or verbs. Results showed that stress typicality effects emerge in the left hemisphere only. These results are theoretically significant and affect the modeling of spoken word recognition by demonstrating an important role for the left hemisphere in conveying accurate stress patterns *prior* to lexical access and showing that prosodic information assists in reducing the set of potential candidates *during* lexical access. They also highlight the interplay of prosody and grammatical category.

1. Introduction

All the world's languages exhibit some kind of rhythm or 'prosody' by incorporating features such as stress and/or tonal variation. These features can be marked by a number of acoustic parameters including F0, duration and amplitude. Prosody plays a central role during language acquisition. It has recently been reported that the inability of 5-month-old infants to discriminate word stress patterns in German has been associated with later diagnosis of Specific Language Impairment (Weber, Hahne, Friedrich & Friederici, 2005). Deficits in stress processing at the single word level have also been clearly linked with Autism Spectrum Disorders (Paul, Augustyn, Klin & Volkmar, 2005), Alzheimer's disease and Parkinson's disease (see Wymer et al., 2002). However, prosodic processing, particularly at the neural level, remains poorly understood and has been overlooked or underspecified in most cognitive/computational models of human language processing.

One of the gains made in previous research is the distinction between linguistic vs. affective prosody and word-level vs. sentence prosody. The current study focussed on linguistic word-level prosody and provides

a novel and significant contribution by examining hemispheric involvement in the recognition of disyllabic English words with *typical vs. atypical patterns of lexical stress* in non-impaired adult participants. It also contributes to a growing interest in the interplay between prosody and grammatical category information.

Lexical stress refers to the opposition of stressed and unstressed syllables within single words. For languages such as English it is not possible to determine the stress pattern of all words in advance. However, it is possible to identify *characteristic* ('typical') patterns of stress. Notably, there is more than one way to determine stress typicality in English. Looking at all disyllabic words, most exhibit first syllable stress (e.g., 'Racket') and can be considered typically stressed. Words with second syllable stress (e.g., 'raCOON') can be considered as atypically stressed. Some studies have reported typicality effects using this definition (Mattys & Samuel, 2000). However, grammatical category was not considered in those studies eliminating the potential to find differences across nouns and verbs.

Grammatical category is important because there are striking differences in patterns of lexical stress

across these categories in English: Whereas disyllabic nouns exhibit first syllable stress, most disyllabic verbs exhibit second syllable stress (Kelly & Bock, 1988; Sereno, 1986). Thus, 'ZEbra' and 'exPLAIN' can be considered to be typically stressed, while 'girAFFE' and 'LISten' can be considered atypically stressed (note the important distinction between *atypical* stress and *incorrect* stress: the last two examples are words with atypical stress patterns - but are not mis-stressed). The origins of these differences may relate to specific rhythmic biasing contexts created by word order and inflectional patterns in English that affect nouns and verbs in different ways (Kelly, 1992). Both native and non-native speakers of English are sensitive to these stress differences across nouns and verbs in a variety of tasks and in both the visual and auditory modalities (e.g., Arciuli & Cupples, 2003; 2004; 2006).

A key aim of the current study was to determine *where* linguistic word level prosody is processed - in particular, whether there is differential hemispheric involvement with regard to sensitivity to stress typicality. A review of current theories suggests three possibilities: that prosodic processing is not lateralised but is subserved by subcortical regions, that all aspects of prosody are processed in the right hemisphere, that some aspects of prosody are left lateralised while others are right lateralised (see Baum & Pell, 1999 for review). The third possibility is embodied in two current theories. The functional lateralisation theory posits that affective/emotional prosody is processed in the right hemisphere while linguistic prosody is processed by the left (Van lancker, 1980). This may, in part, be due to the presence of certain acoustic cues (i.e., right dominance for frequency cues and left dominance for temporal cues) (Van lancker & Sidtis, 1992). An alternative theory concerning hierarchical levels of processing suggests that sentence-level prosody employs global processes controlled by the right hemisphere while word-level prosody concerns local processes in the left. This difference may relate to the size of the temporal domain associated with sentence vs. word-level processing: long vs. short integration windows (see Gandour et al., 2003).

Previous studies have provided inconsistent results. It has been found that patients with right hemisphere damage have problems discriminating stress contrasts when presented with noun compounds and noun phrases - 'GREENhouse' vs. 'green HOUSE' (Weintraub, Mesulan & Kramer, 1981). However, it has also been reported that patients with left-hemisphere damage have difficulty with a word-picture matching task - 'OBject' vs. 'obJECT' (Walker, Daigle & Buzzard, 2002). Other patient studies (Emmorey, 1987; Vanlancker-Sidtis, 2004) have used noun compounds and noun phrases and found an important role for the left hemisphere in the processing of linguistic word-level prosody. Recently, a study of Croatian that tested non-impaired participants showed no hemispheric specialisation for a single minimal word pair distinguished only by stress (Mildner, 2004).

None of these previous empirical studies examined hemispheric processing of stress typicality. In addition, in terms of processes operating at the single word level conducted in English, a closer look at previous empirical studies reveals that the majority of them were not, strictly speaking, limited to processing within single words because they compared words and word phrases ('green HOUSE' and 'hot DOG'). Second, they relied on very similar sets of stimuli while it is desirable to examine a variety of stimuli (including non nominal exemplars) to enable results to be generalisable. Third, the use of nouns and noun compounds makes it difficult to control for lexical variables such as word frequency. Fourth, some of these studies included stimuli that were created via speech segmentation (somewhat 'unnatural'). Finally, previous studies using word-picture matching have not controlled for visual complexity and familiarity. For these reasons, a focus on typically vs. atypically stressed words offers more control in the examination of hemispheric contributions to linguistic word-level prosody. In addition, we were interested in investigating processing in non-impaired participants (in order to ascertain a kind of 'baseline' which may, in future studies, be used to determine more precisely how far patients deviate from 'normal' processing) and in identifying *when* these prosodic effects arise (especially with regard to lexical access).

Widely accepted models of spoken word recognition (e.g., Cohort model: Marslen-Wilson, 1990; TRACE: McClelland & Ellman, 1986; Shortlist: Norris, 1994) do not provide adequate detail concerning the role of prosodic information, in particular, the mechanisms by which stress typicality might affect early recognition processes. Rather, they focus on the contribution of phonemic information. However, there is a growing amount of empirical data that indicates that prosodic information, like phonemic information, does contribute to constraining lexical access. Recently, such effects have been reported during word recognition in Spanish (Soto-Faraco, Sebastian-Galles, & Cutler, 2001) and in Dutch (Donselaar, Koster & Cutler, 2005).

We used dichotic listening to assess hemispheric processing. During dichotic listening, a target is presented to one ear while a competing stimulus (in this case, a reversed version of the target) is presented to the other ear simultaneously. When competing stimuli have a high degree of temporal and spectral overlap there is suppression of ipsilateral pathways and enhancement of contralateral pathways such that stimuli are projected from one ear to the opposite hemisphere for processing (i.e., right ear = left hemisphere; left ear = right hemisphere). Random presentation of stimuli reduces attentional strategies because participants cannot anticipate to which ear the target will be presented. The paradigm is the most frequently used technique in studies of hemispheric processing of language (O'Leary, 2002) and converging evidence from both neuroimaging (e.g., Thomsen, Rimol, Erslund, & Hugdahl, 2004) and ERPs (e.g., Eichele, Nordby, Rimol, & Hugdahl, 2005) confirms

that dichotic listening is an effective method of investigating hemispheric processing.

2. Naming Experiment

We expected typically stressed words to elicit advantaged processing compared to atypically stressed words. If there is hemispheric specialisation for the processing of linguistic word-level prosody we expected to observe a significant interaction whereby this effect would emerge in one hemisphere only.

2.1. Methods

Twenty-six right-handed English speakers from the Bowdoin College community participated in exchange for monetary compensation. The Edinburgh Handedness Inventory was used to ascertain right-handedness (Oldfield, 1971). Experimental items consisted of the same 40 disyllabic words used in a previous study (Arciuli & Cupples, 2004): 20 were typically stressed (10 nouns – e.g., “tension”; 10 verbs – e.g., “comply”) and 20 were atypically (but correctly) stressed (10 nouns – e.g., “technique”; 10 verbs – e.g., “conquer”).

Typically and atypically stressed words were group-wise matched on initial phoneme, spoken, average number of phonemic neighbours and average spoken frequency of neighbours. There were no differences in the uniqueness points of typically and atypically stressed words ($F < 1$).

Stimuli were recorded by a female speaker and resulting sound files were normalised and presented in 44.1KHz 16bit format. The average entire duration of typically and atypically stressed words was 613 msec and 572 msec respectively ($F(1,38) = 1.99$, $p > .10$). For each file we produced a reversed version (target played backwards) to be played simultaneously. As expected, fine-grained analyses showed acoustic differences between words with first syllable stress and words with second syllable stress. Importantly, these differences were consistent across nouns and verbs. A 2 (stress pattern: 1st syllable stress vs. 2nd syllable stress) \times 2 (grammatical category: noun vs. verb) between items ANOVA indicated a significant main effect whereby the duration of the first syllable was longer in words with 1st syllable stress, $F(1,36) = 9.52$, $p = .004$. A second ANOVA indicated that the duration of the second syllable was longer in words with 2nd syllable stress, $F(1,36) = 6.21$, $p = .017$. In separate analyses there were no significant differences on other acoustic measures.

Participants were told they would hear one clear stimulus and one nonsense stimulus played simultaneously to different ears on each trial. Their task was to repeat the word they heard as quickly and accurately as possible. Item presentation and data collection was controlled using E-prime (Schneider, Eschman, & Zuccolotto, 2002). Naming latencies were measured from the onset of the target to the participant’s

vocal response. A microphone connected to a response box was interfaced with the computer signalling that a response was made and the timing for that trial should be terminated. An experimenter recorded participant responses for later analysis of errors.

A typical trial included the presentation of a warning signal (* * * * *) on the computer monitor for 1 sec. Immediately following this, the participant heard the target and responded. After a 1 sec. inter-trial interval the next trial began.

Half of the targets were presented to the participant’s right ear (with the reverse target in the left ear) and half were presented to the left ear (with the reverse target in the right ear). Two lists were created such that presentation of a particular target to the right ear on the first list resulted in that target being played to the left ear on the second list. Participants were assigned to only one list and targets were presented in a random order (i.e., there was no blocking and participants did not know to which ear they should pay attention).

2.2. Results

Trimmed, correct naming latencies are reported in Figure 1.

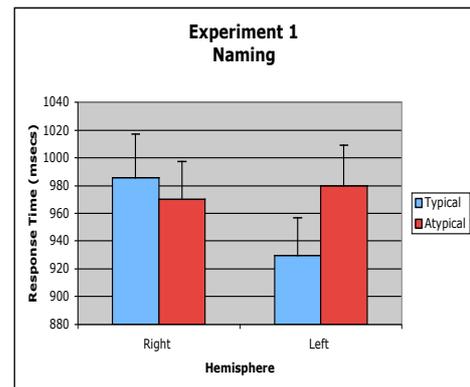


Figure 1. Average correct response times as a function of stress typicality and hemisphere in Experiment 1 (error bars show standard error of the mean).

There was a significant interaction between stress typicality and hemisphere ($F(1,25) = 9.28$, $p = .005$, Cohen’s $f = .282$). Further analyses revealed a significant 50 msec advantage for typically stressed words presented to the right ear/left hemisphere ($t(25) = 3.29$, $p < .005$, Cohen’s $d = .645$). In contrast, there was only a 15 msec difference between typically and atypically stressed words presented to the left ear/right hemisphere which was not statistically significant ($t(25) = -1.04$, $p > .10$, Cohen’s $d = .204$).

There was marginal main effect of hemisphere ($F(1,25) = 3.46$, $p = .07$, Cohen’s $f = .123$) indicating faster naming times for targets presented to the right ear/left hemisphere and no significant main effect of stress typicality ($F(1,25) = 2.68$, $p > .10$, Cohen’s $f = .097$).

As naming involves both recognition and production processes we conducted a second experiment to clarify whether the hemispheric specialisation underlying this effect operates during recognition processes.

3. Classification Experiment

We used a speeded grammatical classification task that did not require verbal output.

3.1. Methods

Thirty-nine right-handed English speakers from the Bowdoin College community participated in exchange for monetary compensation. The inventory and the stimuli were the same as those in Experiment 1. The procedure was similar to that used in Experiment 1 except that participants were asked to determine whether the target stimulus was a noun or a verb (as quickly and accurately as possible). Participants responded by pressing a button on the response box. Response order was counterbalanced such that half of the subjects pressed the “Noun” button with their right hand and the “Verb” button with their left hand and the other half used the reversed order.

3.2. Results

Trimmed, correct response times are reported in Figure 2.

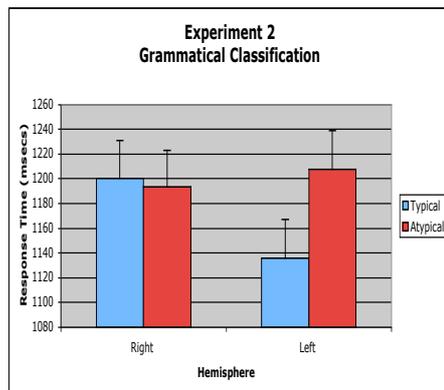


Figure 2. Average correct response times as a function of stress typicality and hemisphere in Experiment 2 (error bars show standard error of the mean).

As in Experiment 1, there was a significant interaction between stress typicality and hemisphere ($F(1,38) = 8.21$, $p < .01$, Cohen's $f = .181$). Further analyses revealed a significant 72 msec advantage for typically stressed words presented to the right ear/left hemisphere ($t(38) = 3.88$, $p < .001$, Cohen's $d = .621$). In contrast, there was only a non-significant 7 msec difference between typically and atypically stressed words presented to the left ear/right hemisphere ($t(38) = -.38$, $p > .50$, Cohen's $d = .061$).

There was a significant main effect of typicality ($F(1,38) = 6.55$, $p < .05$, Cohen's $f = .149$) indicating faster naming times for typically stressed targets but no significant main effect of hemisphere ($F(1,38) = 1.54$, $p > .10$, Cohen's $f = .039$).

4. Discussion

This study addresses questions of significant theoretical interest regarding: hemispheric processing of linguistic word level prosody, the precise locus of stress typicality effects during recognition processes, and, the interplay of prosody and grammatical category information.

The results of Experiments 1 and 2 demonstrate the clear emergence of stress typicality effects during word recognition. The stimuli used in these experiments were tightly controlled on variables known to affect recognition processes - typically and atypically stressed words did not differ significantly in terms of frequency, neighbourhood variables or uniqueness points. These results contribute to the growing number of investigations demonstrating that prosodic information has an important role to play during lexical access in humans. Investigations of Automatic Speech Recognition by machines (ASR) have also reported the usefulness of prosodic information, especially lexical stress, in decoding Dutch (Van Kuijk & Boves, 1999) and English (Wang & Seneff, 2001).

A critical and novel finding is that this typicality effect only emerged for stimuli presented to the left hemisphere. This result runs counter to the claim that there is no hemispheric specialisation for prosodic processing and the claim that all aspects of prosody are processed by the right hemisphere. The result is perhaps most easily accommodated within the cue-dependent framework (Van Lancker, 1980; Van Lancker & Sidtis, 1992). Such a framework suggests left hemisphere dominance for the processing of temporal cues. Appropriately, an acoustic analysis of our stimuli showed that stressed syllables were marked most prominently by syllable duration.

The findings reported here also contribute to recent theorising suggesting that grammatical category distinctions are not purely morphosyntactic and not entirely separable from word-form (Black & Chiat, 2003). Indeed, recent studies have demonstrated that there are clear non-morphological probabilistic differences between nouns and verbs in terms of their phonemic make-up - with regard to length, onset complexity, and manner and place of articulation among other features (e.g., Monaghan, Chater & Christiansen, 2005). In addition, participants are sensitive to extensive non-morphological probabilistic orthographic differences between disyllabic nouns and verbs (Arciuli & Cupples, 2006; in press).

We would like to point out that we do not envisage that listeners determine grammatical status in advance of word recognition or prior to processing stress

patterns. That would surely be impossible. Rather, we propose that stress patterns, in combination with other phonemic information, contribute to a probabilistic distinction (not a strict partitioning) between nouns and verbs within the phonological system itself. We anticipate that grammatical category information may be represented more explicitly at an additional 'level' such as the 'lemma level' or the 'lexico-syntactic level' or via other probabilistic information (such as the semantic distinction between objects/nouns and actions/verbs) - with the proviso that there is a high degree of interaction within the system.

In explanation of these findings, we put forward three critical claims. First, the probabilistic 'clumping' of nouns and of verbs at the phonological level serves to boost activation of a restricted set of possible candidates (through excitation of candidates that share segmental and suprasegmental features of the incoming stimuli and inhibition of competitors that do not share this information). Second, soon after lexical access has begun (and before its completion), spreading activation from other 'levels' (which contain information about grammatical category) feeds back to the phonological level to further narrow the possible set of candidates by enforcing either 'nouniness' or 'verbiness' until the target is recognised. These first two claims account for advantaged processing of typically stressed words. Third, and necessary for explaining the emergence of stress typicality effects in the left hemisphere only, we hypothesise that the spreading activation outlined above proceeds most efficiently in the left hemisphere. We argue that this is because the left hemisphere is specialised for initial detection of stress patterns *prior* to lexical access. When stimuli are presented to the right hemisphere, accurate stress patterns are not determined prior to lexical access and, as a consequence, stress typicality simply cannot contribute to reducing the number of potential candidates for word identification. In contrast, when stimuli are presented to the left hemisphere, accurate stress patterns are determined in a way that enables stress typicality to constrain lexical access.

In sum, this is the first study to demonstrate the emergence of stress *typicality* effects in the left hemisphere and the first to specify the importance of the left hemisphere in determining accurate stress patterns *prior* to lexical access. The results also make an important contribution with regard to two current and contentious debates within cognitive science concerning: a) the role of prosodic information *during* word recognition and b) the multidimensional representation of grammatical category information. Due to the tightly-matched stimuli, non-invasive technique and clear 'baseline' results from non-impaired participants, the experiments/tests reported here may assist in the identification of language dysfunction, in particular left hemisphere dysfunction, in a range of disorders including SLI, Autism, Alzheimer's disease and Parkinson's disease. We are currently pursuing this line of research

5. References

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