# Processing Consequences of Onomatopoeic Iconicity in Spoken Language Comprehension

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**Abstract**

Iconicity is a fundamental feature of human language. However its processing consequences at the behavioral and neural level in spoken word comprehension are not well understood. The current paper presents the behavioral and electrophysiological outcome of an auditory lexical decision task in which native speakers of Dutch listened to onomatopoeic words and matched control words while their electroencephalogram was recorded. Behaviorally, onomatopoeic words were processed as quickly and accurately as words with an arbitrary mapping between form and meaning. Event-related potentials time-locked to word onset revealed a significant decrease in negative amplitude in the N2 and N400 components and a late positivity for onomatopoeic words in comparison to the control words. These findings advance our understanding of the temporal dynamics of iconic form-meaning mapping in spoken word comprehension and suggest interplay between the neural representations of real-world sounds and spoken words.

**Keywords:** Iconicity; Onomatopoeia; Sound Symbolism; Language Processing; Event-Related Potentials

## Introduction

Language comprehension involves the mapping of forms onto meaning representations. In spoken Indo-European languages, the relation between word form and meaning is often opaque and arbitrary. For instance, the French word form *arbre* and the English word form *tree* do not resemble the actual referent that these words denote (De Saussure, 1916). However, word forms can also be *iconic* of their meaning and thereby render the form-meaning mapping largely non-arbitrary. One example is the existence of onomatopoeic words, such as *beep, click,* and *slurp* in English, in which the phonological word form resembles the real-world sound it refers to. Other examples of iconic manners of signification in language can be found in ideophones and mimetics (Dingemanse, 2012; Kita, 1997), in the iconic hand gestures people produce in temporal and semantic alignment with their speech (Kendon, 2004; McNeill, 1992), and in many lexical items in sign languages (Taub, 2001; Thompson, 2011). Current theorizing therefore considers not only arbitrariness but also iconicity a fundamental feature of language (Dingemanse, Blasi, Lupyan, Christiansen, & Monaghan, 2015; Imai & Kita, 2014; Perniss, Thompson, & Vigliocco, 2010; Perniss & Vigliocco, 2014).

In line with its appraisal as a fundamental property of language, several studies have started investigating the processing consequences of iconicity. The majority of studies investigating the role of iconicity in the processing of existing lexical items focuses on sign language (see Perniss et al., 2010; Vinson, Thompson, Skinner, & Vigliocco, 2015). Results are mixed. In lexical decision tasks native signers do not recognize iconic signs at a different speed or accuracy compared to signs with an arbitrary form-meaning mapping (Bosworth & Emmorey, 2010; Klann, Kastrau, & Huber, 2005), which suggests that iconicity does not convey a lexical processing advantage (Bosworth & Emmorey, 2010). In contrast, a facilitatory role of iconicity has been found in picture-sign matching tasks and in picture naming (Grote & Linz, 2003; Ormel, Hermans, Knoors, & Verhoeven, 2009; Thompson, Vinson, & Vigliocco, 2009; Vinson et al., 2015), which suggests that a close mapping between the form and meaning of a lexical item can aid lexical retrieval (Thompson et al. 2009).

The processing consequences of iconicity at the behavioral and neural level in *spoken* language remain largely unclear and much of the work done has used non-words as stimuli (see Lockwood & Dingemanse, 2015). At the behavioral level, studies have followed up on and replicated Köhler's (1929) observation that people associate non-words containing voiceless stops (e.g., *takete* or *kiki*) with spiky shapes and non-words without voiceless stops or containing only continuant consonants (e.g., *maluma* or *bouba*) with curvy shapes (Köhler, 1929; Ramachandran & Hubbard, 2001; Westbury, 2005). At the neurophysiological level, it was found that the brain is sensitive to the sound symbolic congruency between an auditorily presented non-word label and a subsequently presented visual object as early as 160 ms after onset of the visual object, reflected by a significant increase in negative amplitude of an event-related potential (ERP) component in the N2 time-window for congruent compared to incongruent sound symbolic mappings (Kovic, Plunkett, & Westermann, 2010). However, such consistent associations between the acoustic and phonological characteristics of non-words and the shape of objects are interesting, but do not necessarily imply that people process existing iconic lexical items such as onomatopoeic words differently than words with an arbitrary form-meaning mapping.

Neuroimaging studies suggest that the brain represents existing iconic words such as ideophones and onomatopoeic words qualitatively differently compared to non-iconic words. Listening to onomatopoeic words recruits both brain areas involved in the processing of verbal sounds and areas processing non-verbal (animal) sounds (Hashimoto, Usui, Taira, Nose, Haji, et al., 2006). More specifically, additional activation in the right posterior superior temporal sulcus (pSTS) for comprehending iconic words compared to non-iconic words may reflect that iconic words function as both linguistic and non-linguistic symbols (Kanero, Imai, Okuda, Okada, & Matsuda, 2014). These findings thus suggest differences in representation for iconic words compared to words with an arbitrary form-meaning mapping due to the former's connection to sensory information and everyday sensory experience. A performance benefit in auditory lexical decision for onomatopoeic words compared to non-iconic control words in patients with aphasia indeed suggests that iconic word forms may activate their meaning partially via non-linguistic pathways (Meteyard, Stoppard, Snudden, Cappa, & Vigliocco, 2015).

The aim of the current study is to further investigate the processing consequences of iconicity at the behavioral and neurophysiological level in spoken word comprehension, by focusing on onomatopoeia as the textbook example of iconicity in spoken Indo-European languages. Onomatopoeic words recruit a different set of brain regions compared to non-iconic words (Hashimoto et al., 2006), but the behavioral consequences of iconicity in the processing of spoken words remain unclear. Furthermore, the temporal dynamics of these differential patterns of neuronal activation remain unknown. Therefore, in the current study both reaction times and the electroencephalogram (EEG) were recorded while participants performed an auditory lexical decision task that contained onomatopoeic words and matched control words. If iconicity aids in lexical retrieval (cf. Thompson et al., 2009), this may be reflected by faster response times (RTs), higher accuracy, and a less negative deflection in the N400 component for onomatopoeic words compared to control words. Conversely, if iconicity does not convey a lexical processing advantage (cf. Bosworth & Emmorey, 2010) no such effects should be observed. If onomatopoeic words are more effortful to process compared to control words (similarly to ideophones, cf. Lockwood & Tuomainen, 2015), this may lead to slower RTs, lower accuracy, and a late positive effect in the ERPs (Lockwood & Tuomainen, 2015). Finally, if the findings by Kovic et al. (2010) generalize to onomatopoeic iconicity, a difference in amplitude of the N2 component may be expected for onomatopoeic words versus control words.

## Method

### Participants

Thirty-four native speakers of Dutch (28 female; 18-29 years of age, mean age = 22.2) participated in the combined RT and EEG study for monetary reward. They were all right-handed as assessed by a Dutch translation of the Edinburgh Inventory for hand dominance (Oldfield, 1971), had normal or corrected-to-normal vision, and no history of neurological insult or language disability. Data from three participants was excluded from behavioral and EEG analyses due to an error percentage on the behavioral task that exceeded 20%.

### Stimulus Materials

Both RTs and ERPs were recorded to 320 trials that consisted of 160 words (40 Dutch onomatopoeic words, 40 Dutch control words, and 80 Dutch fillers) and 160 Dutch-like nonwords. All 160 words were selected from the SUBTLEX-NL database via the online interface (Keuleers, Brysbaert, & New, 2010; http://crr.ugent.be/isubtlex/). Before recording the stimuli, the onomatopoeic words were matched as carefully and strictly as possible with the control words on a large range of lexical characteristics including word length (i.e., number of graphemes, phonemes, and syllables), frequency (word, lemma, and bigram), dominant lexical class (all taken from SUBTLEX-NL), orthographic and phonological neighborhood density (Coltheart N as taken from Brysbaert, Stevens, Mandera, & Keuleers, in press), age of acquisition, and concreteness (taken from Brysbaert, Stevens, De Deyne, Voorspoels, & Storms, 2014). Separate *t*-tests for each lexical characteristic confirmed that onomatopoeic words and control words did not differ on any of the lexical variables. The 80 fillers were added to keep the proportion of onomatopoeic words presented in the experiment low and to keep the number of nouns and verbs in the experiment similar. As confirmed by the results of a post-experimental questionnaire, this kept the purpose of the experiment unclear to all participants. The 160 Dutch-like nonword stimuli were derived from unused Dutch nouns and verbs that were also taken from SUBTLEX-NL. Nonwords were constructed by Wuggy (Keuleers & Brysbaert, 2010) by changing one to four letters of these existing Dutch words, in line with Dutch orthotactics. Appendix A shows the critical stimuli (onomatopoeic words and control words).

The 320 stimuli were spoken at a normal rate by a female native speaker of Dutch, recorded in a sound proof booth, and digitized at a sample frequency of 44.1 kHz. They were equalized in maximum amplitude using *Praat* software (version 5.2.46; Boersma, 2001). Average stimulus duration was 816 ms ($SD$ = 148). There was no difference in duration between onomatopoeic words ($M$ = 721 ms, $SD$ = 98) and control words ($M$ = 723 ms, $SD$ = 96).

### Rating for Iconicity

To check whether the onomatopoeic words were indeed judged to be more iconic than the control words, 12 native speakers of Dutch (11 female, 18-24 years of age, mean age = 21.1), who did not participate in the main experiment, were asked to rate the 160 word stimuli (i.e. the onomatopoeic words, control words, and fillers) for iconicity. They were seated in a soundproof booth in front of a computer screen. Words were presented to them one at a time via headphones in a randomized way. On the screen they saw a Likert-scale from 1 to 7 where 1 indicated "not iconic at all" (*helemaal niet iconisch* in Dutch) and 7 indicated "very iconic" (*heel erg iconisch* in Dutch). Prior to the start of the rating procedure, instructions explaining the notion *iconicity* (similar to Meteyard et al., 2015) were presented on the screen. Onomatopoeic words ($M$ = 4.83,

$SD$ = 0.53) were rated as significantly more iconic than control words ($M$ = 2.15, $SD$ = 0.77), $t$ (11) = 11.04, $p$ < .001.

## Procedure

After completing informed consent, participants in the main experiment were seated in a comfortable chair at a distance of 100 cm in front of a computer monitor in a shielded, dimly illuminated room. The experiment was programmed using *Presentation* software (Neurobehavioral Systems). Spoken stimuli were presented through EEG-compatible headphones. Before the start of the experiment, written instructions were presented on the screen. Participants were instructed that they would hear spoken stimuli. They were asked to carefully listen to the stimuli and to indicate by pressing a button with the left or right index finger whether the presented item was an existing Dutch word (right finger) or not (left finger). They were asked to make their decisions as quickly and as accurately as possible. Also, they were asked to blink their eyes only when a specific symbol was presented on the screen.

A trial consisted of a fixation cross (200 ms), followed by the spoken stimulus ($M$ = 816 ms) paired with a blank screen (2000 ms in total), followed by a symbol (- -) during which participants could blink their eyes (2000 ms). The response deadline was set to 2000 ms. Responses given after this deadline were considered as errors. The experiment consisted of two blocks of 160 stimuli. Between the blocks participants could have a pause for as long as they wanted. Ten test-items with the same characteristics as the stimuli preceded the main experiment as a practice set.

## EEG recording and analysis

The electroencephalogram (EEG) was recorded continuously from 59 active electrodes held in place on the scalp by an elastic cap. In addition to the 59 scalp sites, three external electrodes were attached to record EOG, one below the left eye (to monitor for vertical eye movement/blinks), and two on the lateral canthi next to the left and right eye (to monitor for horizontal eye movements/saccades). Finally, one electrode was placed over the left mastoid bone and one over the right mastoid bone. All electrode impedances were kept below 20 KΩ. The continuous EEG was recorded with a sampling rate of 500 Hz, a low cut-off filter of 0.01 Hz and a high cut-off filter of 200 Hz. EEG was filtered offline (high-pass at 0.01 Hz and low-pass at 40 Hz). All electrode sites were online referenced to the electrode placed over the left mastoid and re-referenced offline to the average of the right and left mastoids.

ERPs were calculated by averaging the EEG time-locked to a point 100 ms pre-stimulus onset and lasting until 800 ms after the onset of the stimulus. The 100 ms pre-stimulus period was used as a baseline. Trials defined as errors or outliers in the behavioral analyses, and trials containing ocular or muscular artifacts, were not taken into consideration in the averaging process. After removal of trials containing errors, outliers, and artifacts, 87.1% of trials entered the ERP analyses (86.9% of onomatopoeic trials; 87.2% of control word trials). Separate ERPs were computed for the onomatopoeic words and the control words. An approach to data analysis was applied in which the head surface is divided into four quadrants and a vertical midline column of 9 electrodes each, yielding five regions (left anterior, LA; right anterior, RA; left posterior, LP; and right posterior, RP; and the midline column, Midline; see Peeters, Hagoort, & Özyürek, 2015).

The mean amplitudes of the ERP waveforms for each condition per subject were entered into repeated measures ANOVAs with factors Iconicity (2: onomatopoeic words, control words) and Region (5: LA, RA, LP, RP, Midline). Based on the considerations outlined in the Introduction, by-participant analyses were performed on the N2 component (150-200 ms after word onset), the N400 component (350-550 ms after word onset), and a late positive time-window (600-800 ms after word onset).

# Results

## Behavioral (RT and error) analyses

Of the total raw dataset, 5.32 % were errors (wrong responses and responses given after the RT deadline) and therefore removed. In addition, RTs outside the range of 2.5 standard deviations above the participant's mean were considered outliers and were excluded from the analyses (2.26 % of all data). Analyses of variance were performed on the mean RTs and mean error rate per experimental condition in the participant analyses ($F_1$), and on the mean RT and mean error rate per item in the item analyses ($F_2$). Iconicity (onomatopoeic words vs. control words) was a within-participant factor in the participant analyses and a between-item variable in the item analyses.

Table 1: Mean RTs (in ms) and Mean Error Rates (in percentages) per condition in the experiment. Standard deviations are indicated between brackets.

| Condition | Mean RT | Mean Error Rate |
|---|---|---|
| Onomatopoeia | 1006 (125) | 4.68 (6.48) |
| Control words | 1017 (122) | 3.95 (4.17) |
| Fillers | 1058 (111) | 7.42 (6.67) |
| Nonwords | 1193 (127) | 5.28 (3.15) |

Overall, onomatopoeic words ($M$ = 1006 ms) were responded to numerically faster than control words ($M$ = 1017 ms). However, the analysis on the mean RTs showed no significant main effect of Iconicity, $F_1$ (1, 30) = 2.39, $p$ = .132; $F_2$ (1, 78) < 1. Overall, participants made numerically more errors to onomatopoeic words ($M$ = 4.68 %) than to control words ($M$ = 3.95 %). However, also in the error analyses no significant main effect of Iconicity was found,

$F_1$ (1, 30) < 1; $F_2$ (1, 78) < 1. Thus, no behavioral differences were found between onomatopoeic words and control words in auditory lexical decision. Table 1 shows the mean RT and the mean error rate for each condition.

### Electrophysiological analyses

As can be seen in Figure 1, the onomatopoeic words yielded a decrease in amplitude of the N2 component, a less negative-going N400 component, and a late positive deflection compared to the control words.

**N2 time-window (150-200 ms).** The repeated measures ANOVA in the N2 time-window with factors Iconicity (2) and Region (5) showed a significant main effect of Iconicity, $F$ (1, 30) = 6.51, $p$ = .016, $\eta_p^2$ = .178. This effect was not modulated by Region ($F$ < 1).

**N400 time-window (350-550 ms).** The repeated measures ANOVA showed a significant main effect of Iconicity, $F$ (1, 30) = 5.46, $p$ = .026, $\eta_p^2$ = .154. This effect was not modulated by Region ($F$ < 1).

**Late time-window (600-800 ms).** The repeated measures ANOVA showed a significant main effect of Iconicity, $F$ (1, 30) = 4.43, $p$ = .044, $\eta_p^2$ = .129. This effect was not modulated by Region ($F$ < 1).

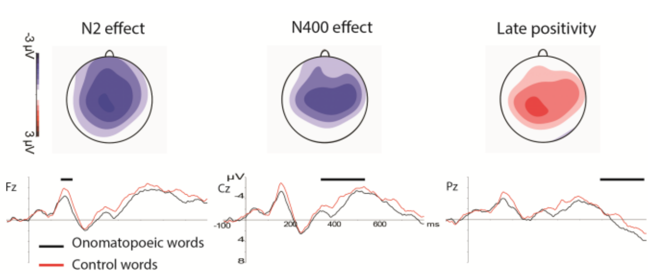


Figure 2: Grand average ERP waveforms time-locked to spoken word onset for a frontal (Fz), a central (Cz), and a parietal (Pz) midline electrode site, reflecting the averaged electrophysiological response to onomatopoeic words (black line) and control words (red line). The three topographic plots show the voltage differences between the two conditions over the scalp for the N2 effect (150-200 ms), the N400 effect (350-550 ms), and the late positivity (600-800 ms).

## Discussion

The current study investigated the processing consequences of iconicity at the behavioral and neurophysiological level in spoken word comprehension. It was found that onomatopoeic words were processed as quickly and accurately as words with an arbitrary mapping between form and meaning. Event-related potentials showed a significant decrease in negative amplitude in the N2 and N400 components and a late positivity for onomatopoeic words in comparison to the control words.

The behavioral results are in line with findings from lexical decision tasks in sign language research, which have shown that native signers do not recognize iconic signs at a different speed or accuracy compared to signs with an arbitrary form-meaning mapping (Bosworth & Emmorey, 2010; Klann et al., 2005). Such findings suggested that iconicity does not convey a lexical processing advantage (Bosworth & Emmorey, 2010). However, the time it takes to make a lexical decision by pressing one of two buttons reflects more than lexical processing alone, as it also involves a decision component and the preparation and execution of a motor response. A more direct measure of processing ease may be the amplitude of the N400 component, particularly when words are presented in isolation. Similar to effects of word frequency on the amplitude of the N400 (Allen, Badecker, & Osterhout, 2003; Van Petten & Kutas, 1990), the decrease in negative amplitude for onomatopoeic words compared to control words suggests facilitated access to the lexicon (Lau, Phillips, & Poeppel, 2008) in case of an iconic mapping between form and meaning (cf. Thompson et al., 2009; Vinson et al., 2015).

This presumed ease of mapping form to meaning for onomatopoeic words as reflected in decreased negative amplitude of the N400 component may even be related to the facilitatory effect of higher word frequency in spoken word comprehension, if one takes into account people's everyday sensory experience of perceiving linguistic and non-linguistic (real-world) sounds. In everyday life people not only encounter onomatopoeic words like *beep, click,* and *slurp* in speech, but they also hear the beeps their alarm clock makes, the clicking of their pen, and the slurping sounds of their partner eating soup - sounds that acoustically resemble their onomatopoeic verbal counterpart (Assaneo, Nichols, & Trevisan, 2011). This is not the case for non-iconic words like *throw* and *write* - the word *write* does not acoustically resemble the sounds produced by the process of writing. People's experiences with hearing real-world non-linguistic sounds are (understandably) not taken into account by measures of lexical frequency in psycholinguistic databases, thereby underestimating the frequency with which onomatopoeic sounds (i.e. the sum of verbal and non-verbal experiences) are encountered in everyday life.

But why then did onomatopoeic words not yield faster reaction times than control words? One possible explanation is again related to the fact that onomatopoeic words are so strongly linked to real-world sounds. In an fMRI study, Hashimoto et al. (2006) found that listening to onomatopoeic words recruits brain areas involved in the processing of both verbal sounds and non-verbal sounds. Along similar lines, Kanero et al. (2014) suggested that additional activation in the right posterior superior temporal sulcus (pSTS) for comprehending iconic words compared to non-iconic words reflects that iconic words function as both linguistic and non-linguistic symbols (see Thierry, Giraud, & Price, 2003). The dual nature of onomatopoeic words, activating both linguistic representations and non-linguistic real-world sound representations, may lead to a conflict when a lexical decision has to be performed on these stimuli. Non-iconic words are arguably more unambiguously identifiable as lexical items than iconic words that have a strong non-lexical component. At the behavioral level, this may cancel out the earlier benefit for onomatopoeic words as indicated by the N400 difference, yielding statistically similar response times for onomatopoeic and control words in lexical decision. Because of its timing and directionality, it could be that the late positivity in the ERPs reflects this enhanced difficulty in making a post-lexical meta-linguistic decision for onomatopoeic words (see e.g. Holcomb, Grainger, & O'Rourke, 2002).

In addition to the N400 effect and the late positivity, an early difference between onomatopoeic words and control words was found in the amplitude of the N2 component. Notably the directionality of this effect was opposite to the directionality of the effect reported by Kovic et al. (2010) in which congruent (compared to incongruent) sound symbolic mappings elicited larger amplitude in the N2 time-window. This difference in directionality of the effect may be due to the difference in stimuli used across the two studies. Kovic et al. (2010) focused on *cross-modal* mappings between an auditorily presented *non*-word label and a subsequently presented visual object. The current study used existing onomatopoeic words, i.e. verbal sounds that refer to non-verbal sounds - all within the auditory modality.

As outlined above, fMRI evidence suggests that hearing an onomatopoeic word activates not only brain areas involved in the processing of verbal sounds, but also (right-hemisphere) areas such as right pSTS involved in processing real-world sounds, outside of the canonical language network (Hashimoto et al., 2006; Kanero et al., 2014). The N2 effect in the current study not only confirms that onomatopoeic words are indeed processed qualitatively differently from non-iconic control words, but also suggests that the patterns of activation for iconic and non-iconic words start to diverge already during early stages of spoken word comprehension. Similar early effects of iconicity have been observed in the visual domain for ideophones (Lockwood & Tuomainen, 2015). These early processing differences may even be enhanced in everyday communication for words that have marked iconic properties such as reduplication and lengthening of syllables through which they stand out from other words (Dingemanse, 2012; Lockwood & Tuomainen, 2015) as naturally occurring auditory oddball stimuli.

To sum up, the current study found that at the behavioral level onomatopoeic words were processed as quickly and accurately as words with an arbitrary mapping between form and meaning. Complementing neuroimaging studies, decreased amplitude of the N2 component of the ERP for onomatopoeic words suggested activation differences between onomatopoeic words and control words during early stages of spoken word comprehension. The link between linguistic and sensory experience in the case of onomatopoeia may lead to facilitated form-meaning mapping, but render lexical decision more difficult in healthy participants. These findings are consistent with the view that the neuronal architecture supporting language comprehension is not an encapsulated entity but interacts with the neuronal infrastructure engaged in auditory perception more broadly.

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# Appendix A

**Critical stimuli used in the experiment**

Onomatopoeic words: babbelen, bonken, brommen, brullen, fluisteren, galmen, giechelen, gorgelen, grommen, hakken, hik, joelen, kievit, klateren, kletteren, klikken, klotsen, knarsen, knetteren, knisperen, knorren, koekoek, kraken, kreukelen, kuchen, kwaken, kwekken, loeien, miauwen, murmelen, piepen, plof, plonzen, rits, ritselen, sissen, slurpen, spatten, tikken, tjilpen.

Control words: afknippen, afprijzen, beheksen, bewonen, blesseren, blinken, broeden, haag, harsen, heg, hinken, inzepen, kneden, knikkeren, kroelen, kruimelen, mand, metselen, omzomen, onweren, optillen, pluizen, prutsen, rafelen, refrein, reiken, slijmen, slijpen, speuren, spieken, staren, tieren, tutten, uitlenen, vastzitten, vijlen, werpen, wiegen, witlof, zuchten.