The Role of Phonology in Iconicity Effects: Evidence from Individual Differences

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This research was supported by the Natural Sciences and Engineering Research Council (NSERC) of Canada, through a Discovery Grant to PMP.

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Abstract

Growing evidence suggests that, along with arbitrariness, non-arbitrariness exists in language. An example of this is iconicity, in which a word's form resembles its meaning. We investigated whether phonological processing plays a key role in the facilitated processing of iconic language (i.e., in some studies the meanings of iconic words are retrieved more quickly and more accurately). First, we reanalyzed the phonological lexical decision task (PLDT) data from Experiment 2 in Sidhu, Vigliocco, and Pexman (2020), and used accuracy on pseudohomophone trials to gauge extent of phonological processing. Participants with greater pseudohomophone accuracy were found to show larger iconic facilitation. We further tested this relationship with a new PLDT experiment, and collected imitateness ratings for 522 words in order to manipulate the imitateness of the iconic stimuli used. We found again that individual differences in phonological processing interacted with iconic facilitation. Further, these effects were found only for imitative iconic words (i.e., onomatopoeia and ideophones), suggesting that direct imitateness is important to iconic facilitation. These findings suggest phonology plays a key role in iconic facilitation, and that the extent to which an individual engages in phonological processing may affect the strength of observed iconicity effects.

Keywords: iconicity, imitateness, individual differences, language processing, onomatopoeia, phonology

1. Introduction

1.1. Iconicity

A long-held view is that spoken language is arbitrary, such that a word's form (i.e., its orthography, phonology) has no relationship to its meaning (e.g., Hockett, 1960). However, there is growing agreement that iconicity, or a resemblance-based relationship between a word's form and meaning (e.g., Perniss, Thompson, & Vigliocco, 2010), does exist in spoken language. Familiar examples of iconicity include onomatopoeia, in which a word's phonology imitates its referent (e.g., *boom*), or ideophones more broadly, which are words that depict sensory imagery (e.g., *zoom*; Dingemanse, 2012). Iconicity can also be less direct, where the relationship between form and meaning occurs through association or sound symbolism (see Lockwood & Dingemanse, 2015, for a review). For example, in the Maluma/Takete effect (Köhler, 1929) certain phonemes are associated with visual roundness (e.g., /l/, /u/) or jaggedness (e.g., /k/, /t/; Maurer, Pathman, & Mondloch, 2006; Nielsen & Rendall, 2011). Thus, a word like *balloon* could be considered iconic in that it contains round-associated phonemes and refers to a round object (i.e., nonimitative iconicity).

Both arbitrariness and iconicity provide benefits to language. On the one hand, arbitrariness affords language the freedom to develop unconstrained, as there is no need for the form of a word to share any resemblance with its meaning. On the other hand, it has been proposed that iconicity played a role in language evolution, and that there is facilitated learning and processing of iconic words (Imai & Kita, 2014; Nielsen & Dingemanse, 2020; Perniss & Vigliocco, 2014). In sign language, there is a greater potential for iconicity due to the visual and gestural nature of the signs, and indeed the iconicity of sign language is often more readily apparent (Perniss, Thompson, & Vigliocco, 2010; Perniss & Vigliocco, 2014). There is a wealth

of evidence that the processing of iconic signs is facilitated relative to arbitrary signs. For example, Thompson, Vinson, and Vigliocco (2009) found that signers of American Sign Language (ASL) responded faster to matching signs and pictures when the iconic feature of the sign was salient in the picture shown, compared to when it was not. Vinson, Thompson, Skinner, and Vigliocco (2015) replicated the effect found by Thompson et al. (2009) in signers of British Sign Language (BSL), and also found iconic facilitation for sign language in several different task contexts.

There has also been some recent evidence that the processing of iconic words in spoken language is facilitated; however, only a handful of studies have tested this proposal. One study found aphasic patients more accurately read aloud and recognized auditorily presented onomatopoeia (vs. arbitrary words), thus showing an iconic processing advantage for tasks involving the mapping between phonology and semantics (Meteyard, Stoppard, Snudden, Cappa, & Vigliocco, 2015). An EEG study of onomatopoeia found differences in the event-related potentials associated with onomatopoeia versus arbitrary words, suggesting that iconic word processing is qualitatively different from that of arbitrary words, with easier lexical access for iconic words (Peeters, 2016). This study did not, however, find behavioural differences between word types.

Aryani and Jacobs (2018) argued that iconicity effects have rarely been explored in the general lexicon (i.e., beyond onomatopoeia and ideophones). To that end, they explored responses to emotionally-valenced words that were previously found to have sounds that were either high or low arousing (e.g., exciting or calming). In this way they examined effects of nonimitative iconicity in language. They found that responses to iconic words (i.e., words whose arousal matched the arousal of their component phonemes) were facilitated. Following up on this

finding with fMRI, Aryani, Hsu, and Jacobs (2019) found that during a passive listening task, participants showed greater activation in the amygdala for iconic affective words, as well as significant functional connectivity from the left superior temporal gyrus (STG) and left inferior frontal gyrus (IFG) to the amygdala. These findings suggest that there is additional processing associated with iconic affective words that integrates the sound, meaning, and emotional information of these words, and that this may partly account for the iconicity processing advantage in this context.

Recently, Sidhu, Vigliocco, and Pexman (2020) investigated whether iconicity facilitates lexical processing, and whether special links between phonology and semantics might account for this effect by manipulating the requirement for phonological processing in each task. They reported behavioral effects of iconicity in both a visual lexical decision task (LDT; “Is this letter string a word?”) and a phonological lexical decision task (PLDT; “Does this letter string sound like a word?”). In the LDT, responses were faster and more accurate to words higher in iconicity, supporting the notion that iconicity facilitates lexical processing. In the PLDT, pseudohomophones (e.g., *brane*), which have nonword spelling but real-word phonology, are included as stimuli in addition to words and nonwords. Participants are thus encouraged to focus on a word’s phonology, rather than spelling, in the task in order to make correct “sounds like a word” responses to pseudohomophones. Sidhu et al. found that words higher in iconicity were processed faster than arbitrary words in the PLDT. There was also a trend for larger iconicity effects in the PLDT than in the LDT, potentially because the PLDT involves more extensive phonological processing than does the LDT.

1.2. Mechanism for Iconic Facilitation

The studies described above have reported facilitation for iconic words in lexical processing. However, there is still uncertainty as to exactly how this facilitation comes about during lexical processing. For instance, Meteyard et al. (2015) suggested that processing may be facilitated for iconic words through special links between phonology and semantics, which could be in the form of a greater number of connections between phonology and semantics or through direct links between phonology and semantics. Alternatively, the semantic representations themselves may be responsible for an iconicity processing advantage, rather than a link between phonology and semantics. For instance, facilitated processing may arise from a connection between semantic representations of iconic words and the modality-specific features (Meteyard et al., 2015). Or, more simply, it may be that facilitated processing is due to the form of iconic words, such that iconic words have more unique forms than arbitrary words, and this uniqueness benefits processing. The purpose of the present study was to test the importance of phonology in iconic facilitation, which in turn may help point to the locus of the effect.

In addition to those mentioned above, several other studies have highlighted the potentially important role of phonology in iconic facilitation. In an ERP investigation of iconicity, Lockwood and Tuomainen (2015) found a more positive P2 associated with iconic stimuli, which is often associated with phonological processing and multisensory integration. In addition, Vigliocco, Zhang, Del Maschio, Todd, and Tuomainen (2020) hypothesized that an N400 effect should emerge between onomatopoeic and non-onomatopoeic words if there is a direct link between phonology and semantics for iconicity, and indeed this is what they found. The authors suggested that the direct link with phonology enhances the activation of semantic information, leading to a difference emerging in the N400 time window, which is associated with semantic processing (Kutas & Federmeier, 2011).

1.3. Construals of Iconicity

A recent review of the literature suggested three ways in which iconicity can be construed: as a discrete property that is absent or present, as a type of relationship between form and meaning that can come in different kinds, and as a gradient that comes in degrees (Dingemanse, Perlman, & Perniss, 2020). To further investigate the iconicity effect, we adopted the latter two approaches. First, we endeavored to distinguish between different kinds of iconicity. To that end, we included both iconic words that imitated their sound directly (i.e., IMITATIVE ICONICITY), and words that were iconic but did not involve imitation (i.e., NONIMITATIVE ICONICITY). These were compared to arbitrary words, in what will be called our CATEGORICAL ANALYSIS. This allowed insight into how processing might be facilitated differently for different kinds of iconicity, as it may be the case that imitative iconic words that have a more transparent link with semantics through imitation confer a stronger advantage, or conversely, that this processing advantage is no stronger than for iconic words without imitation. In addition, previous work has either focused on imitative iconicity (i.e., onomatopoeia and ideophones; e.g., Meteyard et al., 2015; Peeters, 2016) or nonimitative iconicity (e.g., Aryani & Jacobs, 2018; Revill et al., 2014); no study has manipulated these two kinds of iconicity categorically in the same experiment. Because these two kinds of items involve different mappings from form to meaning (either a directly phonological one, or a mediated one), we reasoned that comparing them in the present study might further help pinpoint the role of phonology in the iconicity effect.

In addition, we also examined iconicity by degrees, in what will be called our CONTINUOUS ANALYSIS. This allowed the exploration of iconicity as a whole, as this approach enabled us to make use of the varying iconicity present in natural language (Dingemanse et al.,

2020). This classification of iconicity as a continuous variable in our analyses preserves one of the important conclusions drawn from the studies that collected the iconicity ratings we used, that is, that iconicity is not an all-or-none phenomenon, but occurs in varying degrees within language (Perry, Perlman, & Lupyan, 2015; Winter, Perlman, Perry, & Lupyan, 2017).

1.4. Leveraging Individual Differences

In the present study we further investigated the role of phonology in iconicity effects by examining whether individual differences in the extent of phonological processing were related to differences in iconic facilitation. As is true for most cognitive domains, the focus of lexical processing research is usually on average performance, rather than individual variation, but this variation can often give insight that is lost when examining a group average. There is evidence that individual differences in phonological processing are associated with differences in LDT and PLDT performance. For instance, Unsworth and Pexman (2003) reported that individual differences in reading skill predicted differences in phonological effects in LDT and PLDT performance. It has also been noted that although participants are instructed to focus on whether a letter string SOUNDS like a word in the PLDT, there are differences in how participants perform this task.

There has also been evidence of individual differences in sound symbolism effects. Some special populations show larger sound symbolism effects (e.g., synesthetes in a foreign language guessing task; Bankieris & Simner, 2015), while others show smaller effects (e.g., individuals with Autism spectrum diagnosis in a matching task; Gold & Segal, 2017). In fact, Gold and Segal (2017) found that the DEGREE of Autism symptoms was negatively predictive of sound symbolism effects. With typical adult participants, Revill, Namy, DeFife, and Nygaard (2014) found individual differences in sound symbolism sensitivity were positively related to fractional

anisotropy in the left superior longitudinal fasciculus (LSLF), indicating increased white matter integrity in this region, which is often interpreted as increased structural connectivity. Previous research has associated the LSLF with phonological processing (Vandermosten et al., 2012; Wong, Chandrasekaran, Garibaldi, & Wong, 2011), and it has also been identified as belonging to a main phonological processing pathway (Wong et al., 2011). Because of this finding, Revill et al. suggested that individual differences in phonological processing skills should be investigated in future work, hypothesizing that some people may exhibit a greater iconicity processing advantage due to better implicit utilization of phonological information or engagement in phonological processing. Finally, Lockwood, Hagoort, and Dingemanse (2016) found that sound symbolism sensitivity was related to P3 amplitude, and suggested that “[individual] differences can be used to zoom in on the causal processes underlying sound symbolism and iconicity” (p. 12). Accordingly, we investigated the extent to which individual differences in phonological processing are related to the iconicity effect.

First, we reanalyzed Sidhu et al.’s (2020) PLDT data to see if iconicity effects could be predicted by individual differences in attending to phonology, quantified as accuracy on pseudohomophone trials. This was chosen as our measure of phonological processing, as it is assumed that participants who engage in more processing of the phonology of a pseudohomophone will correctly categorize it as sounding like a word, despite its nonword spelling. Thus, those who perform the task with more extensive phonological processing should have higher accuracy on pseudohomophone trials. Although this is not an explicit measure of phonological processing it can be used to index the individual variability in phonological processing on this silent reading task (i.e., the PLDT). To foreshadow, this reanalysis revealed an interaction between pseudohomophone accuracy on the PLDT and iconicity effects on word

trials, indicating that individual differences in phonological processing were related to the iconicity effect in that experiment. We next attempted to replicate and extend this relationship, by conducting a PLDT experiment with new participants and stimuli.

We used pseudohomophone accuracy as a measure of phonological processing, but acknowledge that this measure could also be driven by participants' overall engagement with the task and/or compliance with task instructions. In order to control for some of this variability we also included a measure of attention to task demands. This was intended to disentangle our measure of phonological processing from more general task engagement. Previous work has shown that responses are faster when a trial (either word or nonword) is preceded by a word vs. a nonword (Lima & Huntsman, 1997; Perea & Carreiras, 2003). According to Lima and Huntsman (1997), this could reflect general inhibition; an inhibitory effect is created in the process of responding to a nonword on trial $n-1$, and that inhibition tends to slow down the response process on the following trial. If a participant is engaged in task demands, there should be a difference in reaction time between trials that follow nonword trials and trials that follow word trials (the $N-1$ NONWORD COST), whereas if a participant is less engaged in task demands, the difference should be minimal. Thus, we included this measure to control for engagement in task demands, and to increase the precision of our phonological processing measure.

2. Re-Analysis of Sidhu et al. (2020)

All analyses were mixed effects regression models, computed using the “lme4” package (Bates, Maechler, Bolker, & Walker, 2015) in the statistical software R (R Core Team, 2018). In each model, we took a confirmatory approach (see Winter, 2019), and fit all fixed effects of interest. We developed each model's random effects structure using the approach suggested by Bates, Kliegl, Vasishth, and Baayen (2015). Code can be found here: <https://osf.io/tqczu/>.

Models always contained random subject and item intercepts and continuous predictors were always standardized.

We reanalyzed the data from Sidhu et al. (2020) Experiment 2 to determine if individual differences in engagement in phonological processing (as measured by accuracy on pseudohomophone trials) in the PLDT predicted effects of iconicity (on word trials). These data were retrieved from <https://osf.io/ue7sv/>. We also included a measure of each participant's engagement with task demands, which was calculated in the following manner, using nonword trials as these were not the dependent variable in the main analysis. We calculated each participant's average reaction time to nonword trials following trials eliciting a WORD response (i.e., $N-1$ WORD trials; $M = 1170.81$ ms) and, separately, to nonword trials following trials eliciting a NONWORD response (i.e., $N-1$ NONWORD trials; $M = 1186.78$ ms) and took the difference between them (i.e., $N-1$ NONWORD COST; RT to $n-1$ nonword trials – RT to $n-1$ word trials). This measure, along with its interaction with iconicity, were also included in the model.

We ran a linear mixed effects model with all control variables included by Sidhu et al. (2020): length, log subtitle frequency (Brysbaert & New, 2009), phonological Levenshtein distance (PLD; Yarkoni, Balota, & Yap, 2008); as well as $n-1$ nonword cost, and the interaction between $n-1$ nonword cost and iconicity. Our predictors of interest were: iconicity (Perry et al., 2015; Winter et al., 2017), participant pseudohomophone trial accuracy, and their interaction. Our dependent variable was word trial reaction time. This revealed a significant interaction between pseudohomophone accuracy and iconicity ($b = -6.87$, $p = .043$), see Figure 1, such that individuals with higher pseudohomophone trial accuracy showed a larger iconicity effect on word trials.

Figure 1. The interaction between pseudohomophone accuracy and iconicity. Model predicted reaction times (in ms) are shown. Low and high pseudohomophone accuracy was defined as scores of one standard deviation below and above the mean.

3. Experiment 1

3.1. Method

3.1.1. Participants. Participants were 83 undergraduate students (78 female) from the University of Calgary, ranging from 17 to 43 years of age ($M = 19.59$ years, $SD = 3.96$ years). This sample size was chosen to be double that of Sidhu et al. (2020), and the exact number was determined through convenience sampling. We used the “simr” package (Green & Macleod, 2016) to simulate the data of Experiment 2 in Sidhu et al. with different sample sizes. This

determined that with 83 participants that experiment would have a power of .82 to detect the interaction between iconicity and pseudohomophone trial accuracy.

Due to technical problems, data for one participant were not collected. Inclusion criteria were English fluency and normal or corrected to normal vision. All participants provided written informed consent prior to the start of the study and completed the study in exchange for partial course credit. Ethics approval was obtained from the Conjoint Faculties Research Ethics Board of the University of Calgary.

3.1.2 Stimuli. The stimuli were 120 words, 60 pseudohomophones, and 180 nonwords. More details about each stimulus type are presented in Table 1. See Appendix and <https://osf.io/tqczu/> for stimuli.

Table 1

Number of Trials and Example Stimuli in the PLDT

Stimulus Type	Number of Trials	Example Stimuli
Word	120	
Arbitrary	40	<i>faucet, sock</i>
Nonimitative Iconic	40	<i>glimmer, swirl</i>
Imitative Iconic	40	<i>meow, screech</i>
Pseudohomophone	60	
Arbitrary-based	20	<i>chane, noat</i>
Nonimitative Iconic-based	20	<i>glauce, tynee</i>
Imitative Iconic-based	20	<i>beap, slirp</i>
Nonword	180	

3.1.2.1. Words. The word stimuli were of three types: arbitrary words, nonimitative iconic words, and imitative iconic words (i.e., onomatopoeia and ideophones). All word stimuli were selected from a set of published iconicity rating norms (Perry et al., 2015; Winter et al., 2017) in which participants rated words on a scale from -5 (the word sounds like the opposite of its meaning) to 5 (the word was highly iconic), with 0 indicating that the word was arbitrary.

Our chosen arbitrary words had iconicity ratings ≥ -0.5 and ≤ 0.5 ($M = 0.13$). In order to separate candidate iconic words into nonimitative and imitative iconic word types, we collected imitateness ratings for 522 iconic words (i.e., those with iconicity ratings ≥ 2.0). A separate group of participants ($N = 92$) were each presented with a randomly chosen set of 200 of the 522 iconic words, and were asked to rate the extent to which each word imitated the sound of its referent on a five-point scale (1 = “not at all imitative”; 5 = “very imitative”). Each word was rated by a minimum of 21 participants. These ratings are available here: <https://osf.io/tqczu/>. For correlations between these ratings and other lexical and semantic variables see Table 2. We defined nonimitative iconic words as those with imitateness ratings ≤ 2.0 ($M = 1.71$), and imitative iconic words as those with imitateness ratings ≥ 3.0 ($M = 3.64$).

Table 2

Correlations Between Imitativeness Ratings and Lexical-Semantic Variables

Variable	Correlation with Imitativeness
Iconicity	.62***
Length	-.18***
Frequency	-.12**
OLD	-.25***
PLD	-.29***
SER	.20**
ARC	-.31***
AoA	-.06
Valence	-.05
Valence Extremity	-.10

Note. Frequency is log subtitle frequency (Brysbaert & New, 2009), OLD is orthographic Levenshtein distance (Yarkoni et al., 2008), PLD is phonological Levenshtein distance (Yarkoni et al., 2008), SER is sensory experience rating (a measure of evoked sensory experience; Juhasz & Yap, 2013), ARC is average radius of co-occurrence (a measure of semantic neighbourhood density; Shaoul & Westbury, 2010); AoA is age of acquisition (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2013); valence ranges from negative to positive (Warriner, Kuperman, & Brysbaert, 2012); valence extremity is the absolute value of valence. ** $p < .01$, *** $p < .001$.

We then selected 40 arbitrary, 40 nonimitative iconic, and 40 imitative iconic words to be used as stimuli, using SOS software (Armstrong, Watson, & Plaut, 2012) in MATLAB

(R2018b). Word types were matched on length, log subtitle word frequency (Brysbaert & New, 2009), orthographic Levenshtein distance (OLD; Yarkoni et al., 2008), phonological Levenshtein distance (PLD; Yarkoni et al., 2008), concreteness (Brysbaert, Warriner, & Kuperman, 2014), age of acquisition (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012), mean bigram frequency (Balota et al., 2007), sensory experience ratings (Juhasz & Yap, 2013), feedforward consistency (Yap, 2007), number of phonological neighbours (Balota et al., 2007), and number of homophonic words. We also ensured that nonimitative and imitative iconic words were significantly different on rated imitateness. See Table 3 for characteristics of each word type.

Table 3

Mean (SD) of Lexical Variables for Each Word Type in Experiment 1

	Arbitrary	Nonimitative Iconic	Imitative Iconic
Iconicity	0.13 (0.26)	2.43 (0.46)	3.35 (0.50)
Imitateness	–	1.71 (0.18)	3.64 (0.48)
Length	4.88 (1.11)	4.83 (0.96)	4.78 (0.97)
Frequency	2.41 (0.55)	2.39 (0.73)	2.29 (0.52)
OLD	1.76 (0.50)	1.71 (0.32)	1.76 (0.47)
PLD	1.54 (0.48)	1.45 (0.28)	1.48 (0.38)
Concreteness	3.92 (1.21)	3.80 (0.75)	3.81 (0.52)
AoA	6.93 (2.34)	7.16 (2.46)	6.95 (1.96)
Mean Bigram Frequency	1348.53 (680.77)	1380.83 (689.85)	1316.45 (802.81)
SER	3.58 (1.25)	3.49 (0.80)	3.71 (0.68)
FFC	0.82 (0.25)	0.82 (0.26)	0.84 (0.25)
Phonological Neighbours	10.68 (8.94)	10.28 (7.29)	11.63 (9.37)

Note. Frequency is log subtitle word frequency; OLD is orthographic Levenshtein distance; PLD is phonological Levenshtein distance; AoA is age of acquisition; SER is sensory experience rating; FFC is feedforward consistency; Phonological Neighbours is number of phonological neighbours.

3.1.2.2. Pseudohomophones. The 60 pseudohomophones were created by selecting 20 arbitrary, 20 nonimitative iconic, and 20 imitative iconic words not used in the final word lists, and changing the spelling of these words (e.g., *sigh* to *sye*). Each pseudohomophone used a

spelling to sound mapping that existed in English. The three categories of pseudohomophones were matched on length and number of orthographic neighbours (Coltheart's N; Coltheart, Davelaar, Jonasson, & Besner, 1977).

3.1.2.3. *Nonwords.* The 180 nonwords were matched with the 120 words and 60 pseudohomophones on length, number of orthographic neighbours (Coltheart's N; Coltheart et al., 1977), mean bigram frequency (Balota et al., 2007), and number of syllables, using SOS software.

3.1.3. Procedure. Each participant completed the PLDT individually, seated in front of a computer screen, wearing sound-attenuating headphones. The experiment was presented to participants using E-Prime (Psychology Software Tools, Pittsburgh, PA). Participants were presented with letter strings one at a time in size 20 font. Their task was to decide whether each letter string sounded like a real word, regardless of spelling. Responses were made by pressing one of two keys, either the '/' key with their right index finger ("sounds like a real word"), or the 'Z' key with their left index finger ("does not sound like a real word"). Before beginning the experimental trials, participants completed 30 practice trials. If participants had five or more incorrect responses during the practice trials, the researcher repeated the task instructions and the participant completed the practice trials again.

Each trial began with the presentation of a central fixation cross for 400 ms, followed by a blank screen for 200 ms, and then presentation of the target letter string. Each letter string remained on screen until a response was made, after which a 550 ms blank screen appeared, followed by the start of the next trial. If an incorrect response was made, the word "Incorrect" appeared on screen and a sound was played through the headphones during the post-stimulus

blank screen. The stimuli were presented in two blocks, with a break between the blocks. Stimuli were presented in random order, with an equal proportion of each stimulus type in each block.

4. Results

4.1. Reaction Time

Analyses were conducted on real word trials with a correct response. We removed trials with a latency less than 200 ms or greater than 3,000 ms, and trials with latencies greater than 2.5 standard deviations from each participant's mean (altogether 3.29% of trials).

4.1.1. Categorical iconicity. We ran a linear mixed effects regression predicting word trial reaction time. As in the main analysis of Sidhu et al. (2020) we removed participants who performed poorly on pseudohomophone trials. We defined this as worse than chance accuracy on pseudohomophone trials ($p < .05$). Sixteen participants met this criterion, leaving 66 participants for analysis. We included the control variables: length, log subtitle frequency (Brysbaert & New, 2009) and PLD (Yarkoni et al., 2008). Our predictor of interest was word type (i.e., arbitrary, nonimitative iconic, and imitative iconic; dummy coded with arbitrary words as the reference category). This analysis revealed nonsignificant effects of iconicity for both imitative iconic ($p = .17$) and nonimitative iconic words ($p = .78$), see Table 4. See supplementary material for analyses of pseudohomophone trials.

Table 4

Linear Mixed Effects Regression Model Predicting PLDT Word Trial Reaction Time with Categorical Iconicity

Fixed Effect	<i>B</i>	<i>SE</i>	<i>t</i>	<i>p</i>
Intercept	747.85	13.81	54.17	< .001***
Control Variables				
Length	5.93	6.38	0.93	.35
Frequency	-42.61	5.57	-7.65	< .001***
PLD	6.14	6.50	0.94	.35
Predictor Variables				
Type (Nonimitative Iconic)	3.55	12.87	0.28	.78
Type (Imitative Iconic)	-17.86	12.88	-1.39	.17
Random Effect	<i>s</i> ²			
Item Intercept	2569			
Subject Intercept	7133			

Note. Frequency is log subtitle frequency, PLD is phonological Levenshtein distance. *** $p < .001$.

We next turned to our main focus, the individual differences analysis, examining the interaction between pseudohomophone accuracy and iconicity. We included all participants regardless of their overall pseudohomophone accuracy in order to sample fully from that dimension. We ran a version of the above analysis which also included each participant's pseudohomophone accuracy ($M = 75.00$, $SD = 13.03$), along with its interaction with word trial

iconicity. We also included each participant's $n-1$ nonword cost ($M_{N-1 \text{ NONWORD}} = 1225.34$, $M_{N-1 \text{ WORD}} = 1190.26$) and its interaction with iconicity. In the calculation of $n-1$ nonword cost, nonword trials were cleaned in the manner described for real word trials.

This analysis revealed a marginally significant interaction between imitative iconic words and pseudohomophone accuracy ($p = .054$). The nature of this was that participants with higher pseudohomophone accuracy responded faster to imitative iconic words relative to arbitrary words, see Figure 2. The interaction was not significant for nonimitative iconic words ($p = .66$), see Table 5. Importantly, participants' $n-1$ nonword cost did not interact with their response latencies to imitative iconic words ($p = .95$) nor nonimitative iconic words ($p = .54$). Supplementary analyses revealed that none of length ($p = .65$), frequency ($p = .11$), nor PLD ($p = .33$) interacted with pseudohomophone accuracy.

Table 5

Linear Mixed Effects Regression Model Predicting PLDT Word Trial Reaction Time with Categorical Iconicity and Pseudohomophone (PH) Accuracy X Iconicity Interaction

Fixed Effect	<i>B</i>	<i>SE</i>	<i>t</i>	<i>p</i>
Intercept	743.70	12.23	60.79	<.001***
Control Variables				
Length	7.01	6.09	1.15	.25
Frequency	-43.84	5.32	-8.25	<.001***
PLD	6.90	6.20	1.11	.27
<i>n</i> -1 Nonword Cost	23.49	9.72	2.42	.02*
<i>n</i> -1 Nonword Cost x Type (Nonimitative Iconic)	3.35	5.46	0.61	.54
<i>n</i> -1 Nonword Cost x Type (Imitative Iconic)	-0.33	5.44	-0.06	.95
Predictor Variables				
Type (Nonimitative Iconic)	5.01	12.27	0.41	.68
Type (Imitative Iconic)	-11.09	12.28	-0.90	.37
PH Accuracy	8.96	9.74	0.92	.36
PH Accuracy x Type (Nonimitative Iconic)	-2.43	5.45	-0.45	.66
PH Accuracy x Type (Imitative Iconic)	-10.50	5.45	-1.93	.054
Random Effect	<i>s</i> ²			
Item Intercept	2409			
Subject Intercept	6125			

Note. Frequency is log subtitle frequency, PLD is phonological Levenshtein distance, PH is pseudohomophone. * $p < .05$, *** $p < .001$.

Figure 2. The interaction between pseudohomophone accuracy and word type. Model predicted reaction times (in ms) are shown. Low and high pseudohomophone accuracy was defined as scores of one standard deviation below and above the mean.

4.1.2. Continuous iconicity. We next ran versions of the above analyses in which iconicity was treated as a continuous variable. This revealed a nonsignificant effect of iconicity ($p = .15$), see Table 6. The analysis exploring the interaction between pseudohomophone accuracy and word iconicity revealed a significant interaction ($p = .029$), see Figure 3 and Table 7. The nature of this was that participants with higher pseudohomophone accuracy showed a

larger effect of iconicity on word trials. Importantly, participants' $n-1$ nonword cost did not interact with iconicity ($p = .94$).

Table 6

Linear Mixed Effects Regression Model Predicting PLDT Word Trial Reaction Time with Continuous Iconicity

Fixed Effect	<i>B</i>	<i>SE</i>	<i>t</i>	<i>p</i>
Intercept	743.08	11.63	63.89	< .001***
Control Variables				
Length	6.71	6.37	1.05	.29
Frequency	-42.51	5.57	-7.64	< .001***
PLD	5.17	6.49	0.80	.43
Predictor Variables				
Iconicity	-7.69	5.26	-1.46	.15
Random Effect	s^2			
Item Intercept	2568			
Subject Intercept	7134			

Note. Frequency is log subtitle frequency, PLD is phonological Levenshtein distance. *** $p < .001$.

Table 7

Linear Mixed Effects Regression Model Predicting PLDT Word Trial Reaction Time with Continuous Iconicity

Fixed Effect	<i>B</i>	<i>SE</i>	<i>t</i>	<i>p</i>
Intercept	741.68	9.97	74.37	<.001***
Control Variables				
Length	7.60	6.07	1.25	.21
Frequency	-43.78	5.31	-8.25	<.001***
PLD	6.11	6.19	0.99	.33
<i>n</i> -1 Nonword Cost	24.49	9.21	2.66	.01*
<i>n</i> -1 Nonword Cost x Iconicity	0.16	2.23	0.07	.94
Predictor Variables				
Iconicity	-4.80	5.02	-0.96	.34
PH Accuracy	4.65	9.23	0.50	.62
PH Accuracy x Iconicity	-4.83	2.23	-2.17	.029*
Random Effect	<i>s</i> ²			
Item Intercept	2404			
Subject Intercept	6128			

Note. Frequency is log subtitle frequency, PLD is phonological Levenshtein distance. *** *p* < .001.

Figure 3. The interaction between pseudohomophone accuracy and iconicity. Model predicted reaction times (in ms) are shown. Low and high pseudohomophone accuracy was defined as scores of one standard deviation below and above the mean.

4.2. Response Accuracy

Analyses were conducted on real word trials. The data were trimmed in the same manner as for reaction time, except that here inaccurate trials were included (altogether 4.17% of trials removed).

4.2.1. Categorical iconicity. We ran a logistic mixed effects regression predicting response accuracy, in the same manner as described for reaction time. This revealed more

accurate responses to imitative iconic words than to arbitrary words ($p = .046$). The effect for nonimitative iconic words was not significant ($p = .78$), see Table 8.

Table 8

Logistic Mixed Effects Regression Model Predicting PLDT Word Trial Accuracy with Categorical Iconicity

Fixed Effect	<i>B</i>	$\exp(B)$	<i>SE</i>	Wald's <i>z</i>	<i>p</i>
Intercept	4.77	118.04	0.26	18.46	< .001***
Control Variables					
Length	0.44	1.56	0.15	2.93	.003**
Frequency	0.73	2.07	0.16	4.69	< .001***
PLD	-0.14	0.87	0.14	-0.98	.33
Predictor Variables					
Type (Nonimitative Iconic)	-0.08	0.92	0.29	-0.29	.78
Type (Imitative Iconic)	0.63	1.88	0.32	2.00	.046*
Random Effect	s^2				
Item Intercept	0.53				
Subject Intercept	0.78				

Note. Frequency is log subtitle frequency, PLD is phonological Levenshtein distance. * $p < .05$,

** $p < .01$, *** $p < .001$.

Next we ran the individual differences analysis, in the same manner as for reaction time.

This revealed a significant interaction between imitative iconic words and pseudohomophone

accuracy ($p = .014$). The nature of this was that participants with higher pseudohomophone accuracy responded more accurately to imitative iconic words relative to arbitrary words, see Figure 4. The interaction was not significant for nonimitative iconic words ($p = .71$), see Table 9. Importantly, participants' $n-1$ nonword cost did not interact with imitative iconic words ($p = .14$) nor nonimitative iconic words ($p = .33$). Supplementary analyses revealed that none of length ($p = .23$), frequency ($p = .99$), nor PLD ($p = .83$), interacted with pseudohomophone accuracy.

Table 9

Logistic Mixed Effects Regression Model Predicting PLDT Word Trial Accuracy with Categorical Iconicity and Pseudohomophone (PH) Accuracy X Iconicity Interaction

Fixed Effect	<i>B</i>	<i>exp(B)</i>	<i>SE</i>	Wald's <i>z</i>	<i>p</i>
Intercept	4.55	94.57	0.23	19.68	<.001***
Control Variables					
Length	0.37	1.44	0.13	2.80	.005**
Frequency	0.60	1.82	0.13	4.75	<.001***
PLD	-0.14	0.87	0.13	-1.12	.26
<i>n</i> -1 Nonword Cost	0.34	1.40	0.19	1.83	.07
<i>n</i> -1 Nonword Cost x Type (Nonimitative Iconic)	-0.19	0.82	0.20	-0.98	.33
<i>n</i> -1 Nonword Cost x Type (Imitative Iconic)	-0.30	0.74	0.21	-1.48	.14
Predictor Variables					
Type (Nonimitative Iconic)	-0.06	0.94	0.28	-0.22	.83
Type (Imitative Iconic)	0.28	1.32	0.29	0.97	.33
PH Accuracy	0.38	1.46	0.17	2.23	.026*
PH Accuracy x Type (Nonimitative Iconic)	0.07	1.07	0.18	0.37	.71
PH Accuracy x Type (Imitative Iconic)	0.45	1.58	0.19	2.45	.014*
Random Effect	<i>s</i> ²				
Item Intercept	0.60				
Subject Intercept	0.68				

Note. Frequency is log subtitle frequency, PLD is phonological Levenshtein distance, PH is

pseudohomophone. * $p < .05$, ** $p < .01$, *** $p < .001$.

Figure 4. The interaction between pseudohomophone accuracy and iconicity. Model predicted response accuracy is shown. Low and high pseudohomophone accuracy was defined as scores of one standard deviation below and above the mean.

4.2.2. Continuous iconicity. We next ran versions of the above accuracy analyses in which iconicity was treated as a continuous variable. This revealed a nonsignificant effect of word iconicity ($p = .16$), see Table 10. The interaction between pseudohomophone accuracy and iconicity was nonsignificant ($p = .11$), see Table 11.

Table 10

Logistic Mixed Effects Regression Model Predicting PLDT Word Trial Accuracy with Continuous Iconicity

Fixed Effect	<i>B</i>	$\exp(B)$	<i>SE</i>	Wald's <i>z</i>	<i>p</i>
Intercept	4.98	145.24	0.22	23.19	< .001***
Control Variables					
Length	0.43	1.53	0.16	2.70	.007**
Frequency	0.74	2.10	0.16	4.59	< .001***
PLD	-0.12	0.89	0.15	-0.80	.43
Predictor Variables					
Iconicity	0.18	1.20	0.13	1.39	.16
Random Effect	<i>s</i> ²				
Item Intercept	0.64				
Subject Intercept	0.78				

Note. Frequency is log subtitle frequency, PLD is phonological Levenshtein distance. ** $p < .01$,

*** $p < .001$.

Table 11

Logistic Mixed Effects Regression Model Predicting PLDT Word Trial Accuracy with Continuous Iconicity and Pseudohomophone (PH) Accuracy X Iconicity Interaction

Fixed Effect	<i>B</i>	$\exp(B)$	<i>SE</i>	Wald's <i>z</i>	<i>p</i>
Intercept	4.61	100.14	0.17	26.79	<.001***
Control Variables					
Length	0.37	1.44	0.13	2.77	.006**
Frequency	0.60	1.83	0.13	4.73	<.001***
PLD	-0.14	0.87	0.13	-1.09	.28
<i>n</i> -1 Nonword Cost	0.18	1.19	0.13	1.33	.18
<i>n</i> -1 Nonword Cost x Iconicity	-0.12	0.88	0.08	-1.50	.13
Predictor Variables					
Iconicity	0.06	1.06	0.12	0.49	.62
PH Accuracy	0.55	1.73	0.12	4.38	<.001***
PH Accuracy x Iconicity	0.12	1.13	0.07	1.58	.11
Random Effect			s^2		
Item Intercept			0.62		
Subject Intercept			0.67		

Note. Frequency is log subtitle frequency, PLD is phonological Levenshtein distance, PH is pseudohomophone. ** $p < .01$, *** $p < .001$.

5. Discussion

Our goal was to investigate the source of iconic facilitation in lexical processing. We found that individual differences in phonological processing interacted with effects of iconicity. In particular, when analyzing iconicity categorically, participants with higher pseudohomophone accuracy were faster and more accurate when responding to imitative iconic words (vs. arbitrary words), as compared to those with lower pseudohomophone accuracy. When analyzing iconicity continuously, participants with higher pseudohomophone accuracy had faster reaction times for higher iconicity words, as compared to those with lower pseudohomophone accuracy. These findings suggest that participants who showed more extensive phonological processing during the task, as inferred from their pseudohomophone accuracy, were more likely to show iconicity effects. Importantly, iconicity did not interact with a measure of engagement with task demands ($n-1$ nonword cost), suggesting that the effects of iconicity we observed for some participants could be attributed to phonological processing per se.

Sidhu et al. (2020; see also Meteyard et al., 2015) suggested that the facilitated processing of iconic words could result from special links between phonology and semantics. They found facilitated responding to pseudohomophones with higher iconicity and reasoned that this supports the notion that phonology played a role, especially because an orthographic-semantic link is unlikely to exist for pseudohomophones (Sidhu et al., 2020). Similarly, Aryani and Jacobs (2018) reasoned that their findings of iconic facilitation for affective words may partly be due to a link between phonology and semantics, in addition to a word's emotional information. Sidhu et al. (2020) and Meteyard et al. (2015) theorized that facilitation could also arise from iconic words' semantic representations themselves. The present results are consistent with the former inference, as our finding that a greater extent of phonological processing was

related to iconic facilitation also suggests that phonology is implicated. Our interpretation is that participants who engaged in phonological processing to a greater extent benefited more from the special links between phonology and semantics for iconic words. Of course, several alternative possibilities exist. One is that the benefits of iconic words reside in their phonology alone. Another is that the phonology of iconic words might have extra links to modality-specific information (see Meteyard et al., 2015). Recall, however, that the present word stimuli were matched on phonological properties (i.e., phonological distinctiveness, number of phonological neighbours) and associated sensory experience, so it is less likely that phonology alone or modality-specific links could account for the effects observed here.

Further insight comes from comparing types of iconic words. This manipulation was included so that we could directly compare facilitation effects for iconic words that imitate their meanings and those that do not. We found that individual differences in reliance on phonology were related to more efficient processing of imitative iconic words, but not nonimitative iconic words. Imitative iconic words have phonologies that directly imitate semantics, whereas nonimitative iconic words have phonologies that imitate their semantics through association. It seems that, at least in the context of the current study where both imitative and nonimitative iconic words were presented, only direct links between phonology and semantics benefit when participants engage in more extensive phonological processing. We use “direct links” here to refer to the fact that the connection between phonology and semantics does not need to be ENTIRELY learned from language experience. Further, the relationship is not an arbitrary one in which phonology and semantics are of an entirely different nature, thus requiring mediation (e.g., hidden units in Harm & Seidenberg, 2004). Instead, there is a pre-existing, resemblance-based relationship between phonology and semantics for imitative iconic words.

That phonological processing was only relevant for imitative iconic words might suggest that iconicity effects in lexical processing are restricted to imitative iconic words. Note, however, that effects of nonimitative iconic words have been found in other tasks such as foreign language guessing (e.g., Revill et al., 2015), language learning (e.g., Imai, Kita, Nagumo, & Okada, 2008), and memory tasks (e.g., Lockwood et al., 2016). In addition, Aryani and Jacobs (2018) found that nonimitative iconic words were processed faster on a language processing task. However, note that their results represent a special case of nonimitative iconicity because of their use of affective stimuli. One may also make the case that with their stimuli the mapping between sound and meaning was imitative, in that it relied on the kinds of sounds that are made when individuals are excited or calm (see also Aryani, Conrad, Schmidtke, & Jacobs, 2018). Another relevant point is that in these previous studies, nonimitative iconic words were the sole type of iconic stimuli used. Thus, context may play a role in the iconicity effect. That is, nonimitative iconicity may only be salient enough to affect responses when the task list serves to highlight it. However, these speculations require more systematic testing in future studies. On the whole, the fact that different effects were found for different types of iconicity in the present study provides support for the proposal that there are meaningful distinctions between different types of iconicity (Dingemanse et al., 2020).

Of course, we must be cautious about drawing conclusions regarding different types of iconicity because we did not observe a main effect of iconicity for either type of iconic word in the analyses of response latencies; we did find an effect for imitative iconic words in analyses of response accuracy. The null effect in latency analyses differs from what was found in Sidhu et al. (2020). Notably, the iconicity of iconic items in the present study was lower on average and more varied ($M = 2.89$, $SD = 0.67$) than in Sidhu et al. ($M = 3.20$, $SD = 0.50$). It could be that a

certain threshold of iconicity is required for it to have an effect on lexical processing latencies. Examining the items used in Sidhu et al. also reveals that a greater proportion of their iconic items were imitative as compared to the items in the present study. In addition, unlike in Sidhu et al., word stimuli in the present study were matched on sensory experience rating, number of phonological neighbours, and number of homophonic words, which may have attenuated effects. As behavioural effects of iconicity in language processing tasks have been mixed, with some studies showing an effect (Meteyard et al., 2015; Sidhu et al., 2020) and others not (Peeters, 2016; Vigliocco et al., 2020), it seems fair to assume that iconicity effects in lexical processing tasks are subtle, and vulnerable to factors such as list context, task context, and individual differences among participants.

We must also use caution when interpreting our results with regard to our measures of phonological processing and engagement with task demands. These two measures were generated from the PLDT itself, but ideally would be measured in entirely separate tasks. Notably, these measures were derived from different trials than those on which we tested for the iconicity effect, so there is some separation. Nonetheless, it is possible that these two measures may not solely measure phonological processing or engagement with task demands, but we would still reasonably expect that the measures index these two abilities to some degree. In future research, we would suggest adding separate measures of these variables and confirming their measurement of the intended cognitive processes.

An unanswered question is why some participants seem more able than others to process phonology extensively in the PLDT. It may be that some individuals are less able to focus on phonological information without actually vocalizing; that some individuals may disregard PLDT instructions and focus on other features of the stimuli, such as orthography; or even that

individual differences in a different skill, such as reading (Unsworth & Pexman, 2003), may come into play and affect observed phonological processing.

6. Conclusion

We have shown that individuals who engaged in more extensive phonological processing tended to show more facilitated processing of iconic words. These findings highlight phonology as an important aspect of the iconicity effect in lexical processing.

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Appendix

Arbitrary Words:

aim	cloak	hippo	myth	sock
amber	clown	humid	pear	spirit
argue	corn	image	pudding	spoon
autumn	creed	limbo	pun	tact
beaver	devote	luck	salt	thread
beige	dome	mental	septic	tortoise
birch	faucet	mold	sink	tulip
cape	flower	mug	skirt	yam

Nonimitative Iconic Words:

anchor	drab	hump	punch	sneak
bland	flat	itch	puny	soft
break	frog	jolt	shimmer	strut
coarse	glide	kneel	sleek	sway
cool	glimmer	leech	sleet	swerve
cushion	happy	lump	slime	swirl
dash	hole	mini	slum	tickle
dense	hug	muzzle	snake	wipe

Imitative Iconic Words:

babble	crunch	meow	screech	thud
bang	cuckoo	munch	sizzle	thump
boom	flop	murmur	sniff	tick
chop	gong	pat	splash	whiff
clang	growl	peep	squawk	whine
click	hoot	ping	squeak	yahoo
cough	hush	pop	squeal	yodel
crack	knock	purr	tap	zoom

Arbitrary-Based Pseudohomophones:

apeel	dolfin	kar	phool	swade
chane	ephert	klose	pohl	throthe
cheeta	fleat	noat	sawker	trawley
countee	gote	phit	shair	treck

Nonimitative Iconic-Based Pseudohomophones:

artch	dred	krawl	shourt	spight
baybe	glauce	loup	shyne	trypod
blawk	hoam	proon	skrawni	tynee
brawd	immence	shawk	sparkul	whish

Imitative Iconic-Based Pseudohomophones:

beap	grone	klunk	mumbull	smootch
bleap	humb	kreeking	rore	sye
churp	klank	kwack	shreek	whoof
gergle	klap	mone	slirp	zippurr

Nonwords:

abounts	dacked	givide	minly	slongy
abron	darton	glags	moobe	smain
acbed	dasp	glarm	nem	smip
acroad	decoup	gloodshot	nep	snushwork
alar	dehear	glurry	nust	somb
arp	driss	gogs	oal	spaked
awg	drock	grags	oumcomes	spo
balfs	dunch	granus	pame	spowdrift
beels	eags	graps	peem	stawed
befends	ebboss	grell	phim	steaf
bems	falp	grook	phip	strobe
bleece	fawds	gurb	phomp	surfeb
bracks	feload	gurro	plame	swong
brib	fet	harlep	plaps	swow
brosk	fike	hazette	plew	swuns
brutt	fimit	hearph	plit	taces
bulp	fippo	hesk	plur	tawing
bundit	flam	hetter	porms	telt
bywoy	flept	hindet	proop	thap
cagged	flerp	howers	prump	thove
cano	fligs	hunder	pumin	thox
ceverse	flup	imtrude	quop	tifted
chrode	fodson	jat	ral	tolid
chueezed	folt	jeg	rarts	tord
clarps	fora	jelt	resodes	tuxan
clee	foss	jike	rilt	twut
cless	frells	joms	rofa	ulns
clurns	froad	joot	rort	veed
connod	frug	jub	shile	visty
coupker	fyms	juck	sikon	vit
cowp	gabbage	junny	siluge	vo
cref	galm	kigs	sinpul	vokes
crog	gazzo	laint	skimmud	walp
cronx	ged	lixen	slails	wult
crulk	geuds	loast	slairs	yakes
cug	gite	loubtful	slan	younks