COGNITIVE SCIENCE
A Multidisciplinary Journal

Cognitive Science 41 (2017) 1958–1987

ISSN: 0364-0213 print / 1551-6709 online
DOI: 10.1111/cogs.12438

A Prime Example of the Maluma/Takete Effect? Testing for Sound Symbolic Priming

David M. Sidhu, Penny M. Pexman

Department of Psychology, University of Calgary

Received 22 May 2015; received in revised form 25 May 2016; accepted 18 July 2016

Abstract

Certain nonwords, like *maluma* and *takete*, are associated with roundness and sharpness, respectively. However, this has typically been demonstrated using explicit tasks. We investigated whether this association would be detectable using a more implicit measure—a sequential priming task. We began with a replication of the standard Maluma/Takete effect (Experiments 1a and 1b) before examining whether round and sharp nonword primes facilitated the categorization of congruent shapes (Experiment 2). We found modest evidence of a priming effect in response accuracy. We next examined whether nonword primes affected categorization of ambiguous shapes, using visual (Experiment 3) and auditory primes (Experiment 4). We found that ambiguous shapes were categorized as round (sharp) more often following the presentation of a round (sharp) nonword. This suggests that phonemes may activate related shape information which then affects the processing of shapes, and that this association emerges even when participants are not explicitly searching for it.

Keywords: Sound symbolism; Bouba/kiki effect; Maluma/takete effect; Priming; Crossmodal correspondences

1. Introduction

The study of language has long been a central topic in Cognitive Science. This research has addressed many questions, including how language is learned, how it is used, and its relationship with other aspects of cognition. As a result, a number of principles have been offered to address these questions. For instance, the arbitrariness of language has long been considered one of its defining features (e.g., Hockett, 1963). This describes instances in which there is no relationship between the form of a word—or its

Correspondence should be sent to David M. Sidhu, Department of Psychology, University of Calgary, 2500 University Drive NW, Calgary, AB, Canada, T2N1N4. E-mail: dsidhu@ucalgary.ca

constituent phonemes[1]—and its meaning. To illustrate this, one need only choose a word at random from the dictionary, for instance *chair*. It is difficult to point to any features of the word *chair* that make it an especially good match for its meaning. Instead, it seems to be a completely arbitrary relationship. Evidence of arbitrariness can be found in the fact that different languages can use entirely different forms to denote the same meaning. For instance, the word *chair* is translated to *szék* in Hungarian.

Despite the prevalence and importance (e.g., Monaghan, Christiansen, & Fitneva, 2011) of arbitrariness, there is a growing awareness that nonarbitrariness is also an important aspect of language (see Dingemanse, Blasi, Lupyan, Christiansen, & Monaghan, 2015, for a review). One way that nonarbitrariness emerges is through instances of iconicity, in which the features of a linguistic unit resemble aspects of its meaning (see Perniss, Thompson, & Vigliocco, 2010, for a review). The experiments reported here focus on *sound symbolism*, an instance of iconicity in which there is a connection between sound and meaning. One example of sound symbolism is a class of words known as ideophones (or alternatively mimetics, or expressives) whose sound captures aspects of their meaning.[2] Consider, for instance, the Japanese ideophones *koro* and *goro*, meaning either a light or a heavy object rolling, respectively. Notice how the voiceless /k/ imparts a lightness, whereas the voiced /g/ imparts a heaviness (Westermann, 1927). Although ideophones are rare in English, they appear in many East Asian, South Asian, and sub-Saharan African languages (among others; Imai & Kita, 2014). While English does not include a specific category of iconic words, Perry, Perlman, & Lupyan (2015) found that a corpus of English words was rated as having a higher correspondence between form and meaning than would be expected by chance. In addition, various studies have shown that English speakers are sensitive to iconic relationships in other languages (e.g., Iwasaki, Vinson, & Vigliocco, 2007). Thus, iconicity seems to be a general phenomenon. Importantly, instead of being a linguistic curiosity, Imai and Kita (2014) have proposed that iconicity may bootstrap language learning, by helping children realize that sounds can stand for referents in the world (see Perry, Perlman, & Lupyan, 2015, for evidence of this in English). These authors and others (e.g., Perniss & Vigliocco, 2014) have also proposed that iconicity might have played an important role in the evolution of language.

In parallel to this work on iconicity in existing language, other studies have sought to understand the mechanisms underlying specific relationships between sound and meaning. That is, for instance, to understand why the /k/ in *koro* implies lightness, whereas the /g/ in *goro* implies heaviness. These studies have often used nonwords to examine correspondences between phonemes and dimensions of meaning in a controlled manner. Perhaps the most studied example is the correspondence between certain phonemes and shapes: the so-called Maluma/Takete effect, first alluded to by Wolfgang Köhler (1929).[3] This is the finding that when presented with a pair of shapes—one with rounded features and one with sharp features—and asked which one is a *maluma* and which one is a *takete*, most individuals will pair *maluma* with the round shape and *takete* with the sharp shape (e.g., Maurer, Pathman, & Mondloch, 2006). The effect extends beyond these particular phonemes. Studies have demonstrated that the consonant phonemes /b/, /g/, /l/, /m/, and /n/ all show a correspondence with roundness, while /k/, /p/ and /t/ show a correspondence with sharpness (e.g., Maurer et al., 2006; Nielsen & Rendall, 2011). In terms of vowels, the rounded vowel phonemes /u/ and /o/ (and to a lesser extent /ɑ/) show a correspondence with roundness, while the unrounded vowels /i/ and /eI/ show a correspondence with sharpness (e.g., Maurer et al., 2006).

There is as yet no fully developed explanation for the mechanism at work in the Maluma/Takete effect. Most theorists point to a crossmodal correspondence between some features of the phonemes and their associated shapes. For instance, Ramachandran and Hubbard (2001) point to the similarity between the sharp changes in the outline of sharp shapes and the sharp changes in phonemic inflection in the voiceless stops /k/, /p/, and /t/. In addition, the articulation of phonemes such as /k/ and /t/ involves sharp, abrupt movements of the tongue. Conversely, many of the consonant phonemes that are associated with roundness are sonorant (e.g., the nasal /m/) and do not involve a complete obstruction of, or the creation of turbulence in, the airflow. This could mimic the smooth outlines of round shapes. In addition, the sensations involved in articulating voiced bilabials such as /b/ or /m/ could be perceived as softer than those in sharp consonant phonemes (i.e., voiceless stops). Furthermore, as Ramachandran and Hubbard point out, the vowel phonemes typically associated with roundness involve a rounding of the lips (e.g., /u/). A different explanation that has been put forth for crossmodal correspondences more broadly has to do with features co-occurring in the world (Spence, 2011). In the case of the Maluma/Takete effect, it may be that round globular objects tend to feel softer and smoother than sharp spiky ones. It has also been suggested that the shapes of the letters in typically round and sharp nonwords may contribute to the effect (e.g., compare the shapes of the letters in *maluma* to those in *takete*) because of their similarity with round and sharp shapes, respectively (Cuskley, Simner, & Kirby, 2015; cf. Sidhu, Pexman, & Saint-Aubin, 2016). However, the fact that the effect is observable in preverbal infants and nonliterate cultures (see below) suggests that letter shape cannot be its sole cause. Whatever the underlying cause, when participants are asked to pair nonwords and shapes, they inevitably notice the correspondence and pair the stimuli in a way that is congruent with it.

Since Ramachandran and Hubbard (2001) rekindled interest in the effect, a variety of studies have demonstrated its generalizability. Maurer et al. (2006) discovered that the effect emerges in 2-year-old infants, whereas Ozturk, Krehm, and Vouloumanos (2013) found evidence of it in the looking behavior of 4-month olds (cf. Fort, Weiß, Martin, & Peperkamp, 2013). Imai et al. (2015) demonstrated that 14-month olds were better able to learn congruent versus incongruent nonword–shape pairings (e.g., *moma* vs. *kipi* paired with a round shape). Besides English speakers, the effect has also been shown to emerge in speakers of languages as diverse as Swahili (Davis, 1961) and Italian (Taylor & Taylor, 1962). Remarkably, Bremner et al. (2013) found evidence of the effect in the Himba tribe of Namibia, a culture known for its isolation from outside cultural influences. Finally, the effect has recently been extended to shapes of existing objects (Flumini, Ranzini, & Borghi, 2014) and to first names (Sidhu & Pexman, 2015; Sidhu et al., 2016).

Despite its generalizability, studies on the Maluma/Takete effect have largely depended on explicit forced-choice paradigms in which participants are asked to consciously decide which of a pair of shapes is best suited to a particular nonword label. Thus, studies have used very transparent tasks, relying on conscious deliberation on the part of the participant. Participants are free to use introspection to search for correspondences between nonwords and shapes, to choose the pairing that they judge to be most apt. One could argue that this context encourages the creation of associations that would not exist otherwise, or to the evocation of information that is not regularly involved in processing the nonwords' phonology. Notice the subtle distinction here: While these overt choice tasks reveal a correspondence between nonwords and shapes that may become apparent upon deliberation on the part of the participant, this does not necessarily mean that an association between phonemes and shapes exists outside of this context.

To fully investigate the processes involved in the Maluma/Takete effect, it is important to determine the different conditions under which the associations between phonemes and shapes will emerge (see Lockwood & Dingemanse, 2015; for a recent review of research on the effect). In particular, it is crucial to examine if they exist independent of a task that explicitly calls attention to them. If they do, then these associations should be detectable even when using more *implicit* measures that do not explicitly ask participants about the associations; there are several results suggesting that this may be the case. For instance, a study by Westbury (2005) investigated the Maluma/Takete effect using a lexical decision task. On each trial, participants had to decide whether a presented letter string was a word or a nonword. Letter strings were preceded by, and then presented inside of, either round or sharp frames; letter strings were made up of either round or sharp phonemes (i.e., phonemes typically associated with roundness or sharpness). Results showed that participants were faster to respond to nonwords when they were inside of a congruent frame (e.g., a round nonword inside of a round frame) as compared to an incongruent frame. This demonstrated that congruence between nonwords and shapes can affect performance, even when participants are not actively seeking or assessing a relationship between them.

Parise and Spence (2012) tested the implicit nature of the effect with an implicit association task. This task has been used in social psychology for decades to test for an unconscious association between categories. On each trial participants were either shown a shape (round or sharp) or were auditorily presented with a nonword (round or sharp) that they then had to categorize via button press. In congruent blocks, the round nonword and shape, and the sharp nonword and shape, shared a response button. In incongruent blocks this was reversed such that round nonwords shared a response key with sharp shapes, and sharp nonwords shared a response key with round shapes. Participants were faster to respond in congruent blocks, providing evidence of a more implicit association between round and sharp shapes and nonwords. However, a drawback to this study was that it only used a single exemplar of each type of visual and auditory stimulus (e.g., only one particular round nonword). This naturally leads to the question of whether the results are limited to the specific nonwords used, or if the results reflect a broader effect that generalizes across similar phonemes.

There has also been evidence from ERP studies to suggest an implicit association between nonwords and shapes. In a study by Kovic, Plunkett, and Westermann (2010), participants were taught to categorize creatures that were comprised of either mostly round or mostly sharp shapes. These two categories were either given congruent labels (*dom* for the round creatures; *shick* for the sharp creatures) or incongruent labels (the reverse). Response times were faster for trials with congruent labels, and there was also a larger N400 for participants in the incongruent condition, perhaps indicative of a less robustly consolidated integration of audio and visual information. Similarly, a study by Asano et al. (2015) found a larger N400 when 11-month olds were shown incongruent versus congruent pairs of nonwords and shapes.

One avenue that has yet to be explored is whether an association between nonwords and shapes will emerge in a sequential priming paradigm, with nonwords preceding shape targets. This approach was adopted in this study, to further investigate whether there is evidence for sound symbolic associations between stimuli when participants are not explicitly asked about those associations. In a typical priming experiment, participants are presented with two stimuli sequentially; participants are typically faster to respond to the second stimulus if it is preceded by (i.e., primed by) a related stimulus than if it is preceded by an unrelated stimulus (e.g., faster to respond to *apple* after reading *orange* than after reading *chair*). Priming effects have been explained in terms of spreading activation from primes to related targets (Collins & Loftus, 1975), or similarity in representations of related stimuli (Masson, 1995). Importantly, participants are not explicitly asked about any relationship between the stimuli; instead, a relationship is inferred based on the extent to which one group of stimuli influences responses to another.

Many studies have demonstrated priming for words with similar meanings (e.g., *cherry-apple*; see Lucas, 2000, for a review), and for words that tend to co-occur, or that refer to concepts that co-occur (e.g., *dog-leash*) (see Hutchison, 2003, for a review). Besides these semantic relationships, it is well established that orthographic and phonological relationships between words can lead to priming effects (e.g., Grainger & Ferrand, 1996; Pexman, Cristi, & Lupker, 1999). Going beyond these types of relationships, and getting closer to the topic at hand, a study by Bergen (2004) examined priming effects with phonesthemes—sounds that occur in words with similar meanings. An example of a phonestheme is the onset *gl-*, which occurs in many words with meanings related to light: *gleam*, *glisten*, *glow*. Bergen demonstrated the psychological reality of phonesthemes, by reporting evidence of phonesthemic priming over and above semantic and phonological priming. That is, priming for words sharing a phonestheme was greater than priming for words with similar form and/or meaning. Important to the present topic, a number of studies have demonstrated that priming effects can be observed when primes and targets occur in different modalities, for instance, when using words and pictures (e.g., Alario, Segui, & Ferrand, 2000; Van den Bussche, Notebaert, & Reynvoet, 2009), or haptic and visual stimuli (Easton, Greene, & Srinivas, 1997).

To our knowledge, there is as yet no evidence that the sound symbolic features of linguistic stimuli can lead to sequential priming. That is, for instance, there has been no evidence that processing a sound symbolically round nonword can facilitate the processing of a sequentially presented round visual shape stimulus.[4] Such a finding would be theoretically important, as it would allow us to draw inferences beyond those of previous studies. Because of the fast-paced and sequential nature of a priming task, this would be qualitatively different from what has been observed on self-paced tasks in which participants are asked to pair nonwords with shapes (e.g., Maurer et al., 2006). On these tasks participants are directed to create correspondences between aspects of the nonwords and shapes. This would not be the case in a priming task. In addition, because nonwords would be presented prior to shapes, with a response required only to the shapes, this paradigm would also provide incremental information to previous *implicit* studies on the effect. If it were found that presentation of a nonword affected the processing of a later and separately presented visual stimulus, this could suggest that the nonword activated sound symbolically related information that then influenced processing of the shape.

By utilizing a priming paradigm, we were also able to investigate whether phonemes can sound symbolically impact responses to more ambiguous stimuli. More specifically, we included examination of whether the shape information that is potentially activated by reading a nonword prime would impact responses to an ambiguous shape (i.e., one that is not strongly round or strongly sharp but rather is a mix of round and sharp features). There is some evidence to suggest that the sound symbolic properties of nonwords can impact how ambiguous information is processed (e.g., Topolinski, Maschmann, Pecher, & Winkielman, 2014; Yorkston & Menon, 2004); however, these studies have used slow paced, explicit choice paradigms. Our approach addressed these issues in a more implicit way. In addition, by examining the effect with ambiguous stimuli, we were able to address a common criticism of the effect, which is that it is only observable in the context of carefully crafted image stimuli that are ideal exemplars of roundness and sharpness (see Westbury, 2005, for a review).

In sum, the purpose of this study was to investigate the possibility that the associations between phonemes and shapes will influence responses in a sequential priming task. This was a nonexplicit task, where participants are not tasked with searching for an association between stimuli. The sequential nature of this priming paradigm also allowed us to make inferences about the information that is potentially activated when reading a sound symbolic nonword. We began with two pilot experiments involving a standard Maluma/Takete choice task to replicate the classic effect, evaluate our stimuli, and establish the time course of nonword processing (Experiments 1a and 1b). Using this as a starting point, we created a priming variation in the standard Maluma/Takete task (Experiment 2), before moving to additional priming studies involving ambiguous targets (Experiments 3 and 4).

2. Experiment 1a

We first examined whether the typical Maluma/Takete effect would emerge in the standard forced-choice task using the stimuli we derived from previous studies. This allowed us to pilot the stimuli, to test whether the effect generalizes across the number of items that might be required in a priming task, and to determine the amount of time participants needed to process the nonwords before we used those nonwords as primes in Experiment 2.

2.1. Method

2.1.1. Participants

Participants were 30 undergraduate students from the University of Calgary, who participated in exchange for course credit. For this and for each of the following experiments, prior to taking part in the study, all participants completed a prescreen questionnaire on which they reported their level of English fluency. Only participants who self-reported as "very fluent" or "completely fluent" were eligible to participate. All participants reported having normal, or corrected to normal, vision. Separate groups of participants were recruited for each of the experiments reported here.

2.1.2. Materials and procedure

There were 20 nonword stimuli; half of these were "sharp" in that they contained nonrounded vowels (/i/, /eI/, /ə/) and consonants that were considered sharp in previous studies on the Maluma/Takete effect (/p/, /t/, /k/; e.g., Nielsen & Rendall, 2011). The other half of the nonword stimuli were "round" in that they contained at least one rounded vowel (/o/ or /u/), and consonants considered round in previous studies on the effect (/b/, /g/, /l/, /m/, /n/, /w/; e.g., Nielsen & Rendall, 2011; Maurer et al., 2006).[5]

Ten of these stimuli were used in previous studies on the effect (Köhler, 1947; Maurer et al., 2006), and ten were modifications of these stimuli. These modifications were made to reduce the extent to which orthography was conflated with phonology in the nonword stimuli. To that end we included consonants with "sharp" phonologies but round orthographies (i.e., /p/), as well as consonants with "round" phonologies but sharp orthographies (i.e., /w/). Thus, for example, in addition to the nonword *kuhtay* (Maurer et al., 2006), the modified *puhtay* was included. Likewise in addition to the nonword *maluma* (Köhler, 1947), the modified *waluma* was included. See Table A1 in Appendix A for a full nonword list.

The shape stimuli consisted of 40 shapes created using Adobe Photoshop. Half of these were comprised of round edges and the other half were comprised of sharp edges. The sets of round and sharp shape stimuli were matched in terms of area, height, and width. See Fig. 1 for examples.

Participants were given a brief description of the procedure and then were seated in front of a computer screen. Each trial began with a fixation cross, which was displayed for 500 ms at the center of the screen. This was replaced with a single nonword, which participants were asked to read out loud into a microphone connected to a voice key. The nonword stayed onscreen for 1,500 ms from the beginning of the vocal response before being replaced by two shapes (one sharp and one round), on either side of the computer screen. The participant was asked to decide which of the two shapes was the best match for the nonword they had just read. They made their decision via button press using a button box, and could take as much time as they needed to respond. Their response brought up a blank screen for 500 ms, after which the next trial began. Participants' vocal responses were recorded and later examined to ensure that the spelling of our nonwords generated the desired phonology.

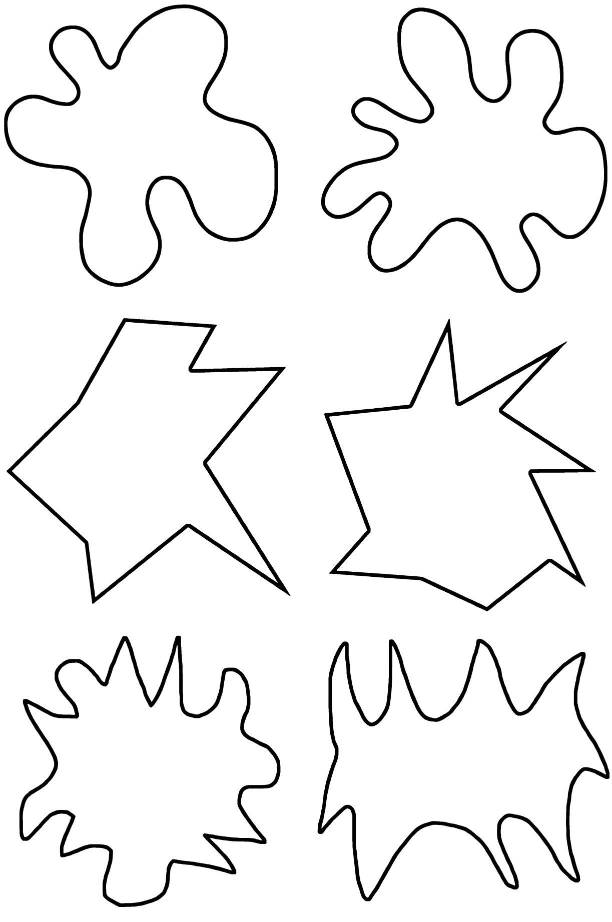

Fig. 1. Examples of round (top), sharp (middle), and ambiguous (bottom) shape stimuli. Note that ambiguous shape stimuli were only used in Experiments 3 and 4.

Participants received two blocks of 20 trials. Each block of trials contained 10 round nonwords and 10 sharp nonwords presented in random order. The position of the round and sharp shapes (i.e., left or right side of screen) was counterbalanced across blocks for each nonword, and the pairing of shapes to nonwords was randomized. Participants' vocal responses were recorded to ensure that the nonwords were pronounced correctly.

2.2. Results

Given concerns that have been raised about the use of ANOVAS when analyzing categorical count data, in this and subsequent experiments, proportional data were analyzed using mixed effects logistic regressions (Jaeger, 2008). Unless otherwise noted, all subsequent analyses included random subject and item intercepts. All mixed effects analyses were conducted using R (version 3.1.2; R Development Core Team, 2014). We examined the

Table 1
The percentage of trials on which participants chose the round shape, for round and sharp nonwords

	Round Nonwords		Sharp Nonwords	
	M (*SD*)	95% CI[a]	*M*	95% CI
Experiment 1a	79.50 (18.02)	[73.53, 85.47]	31.00 (18.86)	[25.03, 36.97]
Experiment 1b	79.33 (16.90)	[73.04, 85.62]	29.83 (19.67)	[23.54, 36.12]

Note. [a]When computing 95% CIs, the method outlined in Cousineau (2005) was used.

effect of nonword type (sharp vs. round) on shape selection with a mixed effects logistic regression in which the dependent variable was the likelihood of selecting the round shape. The model included random subject and item intercepts.[6] The percentages of round shape selections, for round and sharp nonwords, can be found in Table 1. Nonword type was dummy coded such that sharp nonwords were treated as a reference category. Results indicated that participants were 9.78 times more likely to select the round shape when presented with a round nonword than a sharp nonword (Wald $Z = 10.26$, $p < .001$)[7]; see Table 2.

These results demonstrate the standard Maluma/Takete effect: Participants were more likely to select the round shape as the best match for a round nonword than a sharp nonword. Notably, this effect emerged for a wide variety of round and sharp nonword and shape stimuli, and persisted over 40 trials, a great deal more trials than in several previous studies on the effect (e.g., Maurer et al., 2006; Ramachandran & Hubbard, 2001). Thus, the effect appears robust and seems to generalize to a number of nonword items.

3. Experiment 1b

The planned priming experiments involved participants reading the nonwords silently. As such, we wanted to ensure that the Maluma/Takete effect would also emerge for our stimuli under these conditions. Thus, we next ran an identical version of Experiment 1a except that in this case participants were instructed to read the nonwords silently.

Table 2
Summary of logistic regression predicting the likelihood of a round shape selection, in Experiment 1a

Fixed Effect	Coefficient	*SE*	Wald *Z*	*p*
Intercept	−0.85	0.17	−5.12	<.001***
Nonword type	2.28	0.22	10.26	<.001***
Random effect		s^2		
Subject intercept		0.12		
Item intercept		0.14		

Note. $N = 1{,}200$; log likelihood = −667.11; AIC = 1,342.23.
***$p < .001$.

3.1. Method

3.1.1. Participants

Participants were 30 undergraduate students from the University of Calgary who participated in exchange for course credit.

3.1.2. Materials and procedure

The nonword stimuli were the same as those in Experiment 1a except that one duplicate nonword (*tuhpeetee*) was replaced with *puhkeetee*. The shape stimuli were the same as those in Experiment 1a.

The procedure was the same as in Experiment 1a with one exception. Instead of requiring a vocal response from the participant on each trial (to advance from the verbal stimuli to the visual stimuli), nonwords simply appeared onscreen for 2,000 ms before the trial advanced to the visual stimuli. The mean naming latency in Experiment 1a was 1,582.31 ms (SD = 1,247.93), and thus stimuli in Experiment 1b were displayed for 2,000 ms to ensure that participants had enough time to read the nonwords to themselves. The experimenter was in the room throughout the task to ensure that no overt vocal responses were made.

3.2. Results

We again examined the effect of nonword type (sharp vs. round) and length with a mixed effects logistic regression in which the dependent variable was the likelihood of selecting the round shape. The percentages of round shape selections, for round and sharp nonwords, can be found in Table 1. Nonword type was dummy coded such that sharp nonwords were treated as a reference category. The model included random subject and item intercepts. Results indicated that participants were 10.62 times more likely to select the round shape when presented with a round nonword than a sharp nonword (Wald $Z = 8.04$, $p < .001$)[8]; see Table 3.

Thus, even when reading nonwords silently, participants were again more likely to select the round shape as the best match for a round nonword than a sharp nonword.

Table 3
Summary of logistic regression predicting the likelihood of a round shape selection, in Experiment 1b

Fixed Effect	Coefficient	*SE*	Wald *Z*	*p*
Intercept	−0.92	0.21	−4.45	<.001***
Nonword type	2.36	0.29	8.04	<.001***
Random effect		s^2		
Subject intercept		0.03		
Item intercept		0.33		

Note. N = 1,200; log likelihood = −651.99; AIC = 1,311.98.
***p < .001.

4. Experiment 2

We next turned to our main focus, which was an examination of whether there is a more implicit association between phonemes and shapes that can be observed using a sequential priming paradigm. We began with a priming experiment in which the targets were the same types of clearly round or sharp shapes used in Experiments 1a and 1b. On each trial, participants were asked to read the prime nonword silently and then categorize the target shape. If there is an implicit association between phonemes and shapes, we expected that participants would be more likely to make correct shape categorizations on congruent trials (sharp nonword primes and sharp shape targets, round nonword primes and round shape targets), and might also be faster to make categorization responses on congruent trials.

4.1. Method

4.1.1. Participants

Participants were 31 undergraduate students at the University of Calgary who participated in exchange for course credit.

4.1.2. Materials and procedure

This experiment included the 10 round and sharp nonwords that showed the strongest associations with round and sharp shapes, respectively, in Experiments 1a and 1b. See Table A1 in Appendix A for item-level data from Experiments 1a and 1b. In addition, six "neutral" nonwords were included to keep the proportion of related trials (congruent nonword/shape pairings) below 50% to provide a disincentive for participants who might opt to use the primes strategically. These neutral nonwords were developed in the following way. Twenty pilot participants were given a list of 14 consonant–vowel (CV) nonwords, containing consonants not previously used as either round or sharp, paired with either a round or a sharp vowel. They were asked to pair the nonwords with either a round or a sharp shape, or to indicate that the nonword was not a suitable match for either; the results of this pilot testing are attached as supplementary material in Table S1. The most neutral CV nonwords were combined to form six CVCV nonwords, see Appendix B for a list of the neutral nonwords used. Shape stimuli consisted of 26 images with rounded edges and 26 images with jagged edges, developed in the same manner as those in Experiment 1a.

Participants were given a brief description of the procedure and then were seated in front of a computer screen. They were shown examples of round and sharp shapes (although these labels were never used in the instructions or training) and taught which response button was associated with each type of shape. Assignment of response buttons to shapes was counterbalanced across participants. Participants next completed six practice trials that consisted of neutral nonword primes (different from those used in the experiment proper) and either round or sharp shape targets to be categorized. After completing the practice trials, the experiment proper began.

Each trial consisted of a nonword prime, followed by a shape to be categorized. At the beginning of each trial, participants saw a fixation cross in the middle of the screen for 1,000 ms, after which a nonword prime appeared for 1,500 ms. Participants were instructed to read the nonwords silently to themselves and were encouraged to "pay close attention to [the] nonwords because [they] will be asked to use them later." Following the nonword presentation there was a blank screen for 500 ms, after which a shape appeared in the middle of the screen. The participant's task was to categorize the shape as either round or sharp via button press as quickly and as accurately as they could. After making their response, the shape disappeared, and following a 1,000 ms blank screen the next trial began. Note that participants only had to make a response to the shape stimuli; they did not have to perform any task with regards to the nonwords; we simply said the nonwords might be important later. This may have led to a relatively shallow processing of nonword stimuli. Although this could potentially make it more difficult to observe an effect of the nonword primes, it was important to avoid participants actively seeking out a relationship between nonwords and shapes.

Participants were presented with two blocks of 26 trials. There were five trials each of a round/sharp nonword preceding a round/sharp shape (e.g., five trials in which a round nonword preceded a round shape), and three each of a neutral nonword preceding a round/sharp shape. After completing the experiment, participants were given a debriefing questionnaire to assess the extent to which they were aware of its purpose. See Appendix C for a copy of this questionnaire.

4.2. Results

We examined the effect of prime congruence (congruent vs. incongruent) with a mixed effects logistic regression in which the dependent variable was the likelihood of participants making a correct categorization. Mean accuracy for congruent and incongruent trials can be found in Table 4. Prime congruence was dummy coded such that incongruent primes were treated as a reference category. Results indicated that participants were 2.29 times more likely to make a correct categorization following a congruent nonword prime than an incongruent one (Wald $Z = 2.31$, $p = .02$)[9]; see Table 5.

We conducted a supplementary analysis to more carefully examine the degree to which this effect could be considered implicit. Based on debriefing questionnaire responses, we

Table 4
Mean response accuracy (percent correct) and reaction time (measured in milliseconds), on congruent and incongruent trials, in Experiment 2

	Congruent Trials		Incongruent Trials	
	M (*SD*)	95% CI[a]	*M* (*SD*)	95% CI
Accuracy	98.07 (3.80)	[97.01, 99.12]	95.81 (6.84)	[94.76, 96.87]
Reaction time	482.77 (110.26)	[475.43, 490.11]	487.51 (104.75)	[480.17, 494.85]

Note. [a]When computing 95% CIs, the method outlined in Cousineau (2005) was used.

Table 5
Summary of logistic regression predicting the likelihood of a correct shape categorization based on the congruency of the nonword prime, in Experiment 2

Fixed Effect	Coefficient	*SE*	Wald *Z*	*p*
Intercept	3.64	0.35	10.56	<.001***
Congruency	0.83	0.36	2.31	.02*
Random effect			s^2	
Subject intercept			1.12	

Note. N = 1,240; log likelihood = −157.92; AIC = 321.84.
*p < .05, ***p < .001.

removed participants who reported awareness of the experiment's hypothesis. To meet this criterion, participants had to have described the experiment's hypothesis as being that reading round or sharp nonwords would facilitate the processing of round or sharp shapes, respectively. Two participants met this criterion.[10] After removing these participants, results indicated that participants were 2.21 times more likely to make a correct categorization following a congruent nonword prime than an incongruent one (Wald Z = 2.18, p = .03).

In the analysis of reaction time, incorrect trials (3.06%), trials with a latency <200 ms (0.04%), trials with a latency >3,000 ms (no trials met this criterion), and trials on which latencies were more than 2.5 *SD* from the participant's mean (2.50%) were excluded from the analysis. Mean reaction times for congruent and incongruent trials can be found in Table 4. We examined the effect of prime congruence with a linear mixed effects model in which reaction time was the dependent variable. Congruency was dummy coded such that incongruent primes were treated as a reference category. Results indicated that congruency was not a significant predictor of reaction time, b = −4.42, t(1136.20) = −0.66, p = .51.

Thus, these results provide some evidence of an implicit association between certain phonemes and shapes. Participants were not tasked with looking for an association between nonwords and shapes, yet we observed some evidence that such an association exists and that it impacts their responses. That is, participants were significantly more likely to categorize shapes correctly following a congruent nonword prime than an incongruent one. Notably, this effect was also observed after removing participants who reported awareness of the experiment's purpose. Nonword prime congruency had no effect on reaction times.

It must be noted that participants' mean response accuracy was very close to ceiling (>95%). This suggests that categorizing only clearly round and sharp shapes is a very simple task, and it invites the inference that responses in this simple task may be too fast and accurate to be strongly influenced by nonword primes. It is also possible that this ceiling effect may have artificially reduced variance, and could it have led to a Type 2 error in the analysis of accuracy data. As such, a task in which participants categorize only clearly round and sharp shapes may not be the optimal context for investigating sound symbolic priming.

5. Experiment 3

Experiment 2 showed only modest evidence for sound symbolic priming effects in a task where participants classified clearly round or clearly sharp shapes. The task was very easy and it seems that under such conditions sound symbolic priming effects are not strong. In Experiment 3 we devised a more difficult categorization task; our reasoning was that by making the shape categorization task more difficult, we would potentially conduct a more sensitive test of sound symbolic priming. Recall that in the Westbury (2005) study, lexical decisions were faster for stimuli in congruent-shaped frames, but only when those stimuli were nonwords. The effect was not observed for words in congruent-shaped frames. Westbury theorized that an interaction between linguistic stimuli and shape may be relatively slow to develop on each trial, and thus only affected responses to the slower (nonword) trials and not to the faster (word) trials. Although Westbury was referring to a different paradigm, this issue may also be relevant here. That is, target reaction times in the present Experiment 2 may have been too fast to show sound symbolic priming. To make the categorization task more difficult, and potentially slow target reaction times, we included mostly ambiguous shapes for categorization in Experiment 3.

The ambiguity of these shapes may make their categorization more sensitive to sound symbolic priming. Because there are no clearly correct answers in terms of the ambiguous shapes' categorization, nonword primes may have more of an opportunity to affect responses. To be clear, we do not expect a sound symbolic relationship between nonwords and ambiguous shapes per se; instead, if the nonwords activate sound symbolically related shape information, this may in turn affect responses to ambiguous shapes. In particular, participants may be more likely to categorize ambiguous shapes as round following round nonword primes, and as sharp following sharp nonword primes.

5.1. Method

5.1.1. Participants

Participants were 36 undergraduate students at the University of Calgary who participated in exchange for course credit.

5.1.2. Materials and procedure

To thoroughly investigate the possibility of sound symbolic priming for ambiguous shapes, we needed a larger set of nonwords than we had used in the previous experiments. As such, this experiment included a new set of nonwords developed through online pilot testing. Beginning with every possible CVCV and CVCVCV combination of /b/, /m/, /o/, /u/, and /ɑ/ for round nonwords; /t/ and /k/, /i/, /ə/, and /eI/ for sharp nonwords; and /dʒ/, /f/, /h/, /o/, /i/, /ɑ/, and /eI/ for neutral nonwords, a list of over 400 nonwords was generated. Eighty pilot participants then rated subsets of these nonwords in terms of their congruence with round and sharp shapes. Based on these ratings, the 16 most round, sharp, and neutral nonwords were chosen to be included in the experiment proper, see Appendix D.

This experiment included ambiguous shape targets that were created in the following manner. A set of 98 shapes designed to be ambiguous (i.e., comprised of *both* round and sharp features) were created and matched to the previously used stimuli in terms of area, height, and width. In pilot testing, another 24 participants were presented with these shapes, along with purely round and sharp shapes, and were asked to classify each as either round or sharp. The percentage of trials on which each ambiguous shape was classified as round was then calculated, and the 36 shapes that were classified at rates closest to chance were selected as ambiguous shape targets. See Fig. 1, for examples, of these stimuli. In addition to these ambiguous shapes, the stimuli for this experiment also included six round shapes and six sharp shapes as anchors for the categorization task, but our interest was in priming for responses to the ambiguous shapes. Because trials with ambiguous shapes could not be classified as congruent or incongruent (as round and sharp nonwords were neither congruent nor incongruent with ambiguous shapes), our main interest was in whether nonword primes affected the categorization of these ambiguous shapes as either round or sharp.

Participants were given two blocks of 48 trials. Each type of nonword (i.e., round, sharp, and neutral) preceded a round shape twice, a sharp shape twice, and an ambiguous shape 12 times. The procedure was identical to Experiment 2 except that participants were given the extra instruction that some shapes would be more difficult to categorize than others, and to go with their first instinct.

5.2. Results

The fact that trials involving ambiguous shapes could not be classified as congruent or incongruent precluded any meaningful analyses of congruency effects on reaction time for those trials. Thus, our main focus was on whether the categorization of ambiguous shapes would be affected by nonword primes. We examined the effect of nonword type (sharp vs. round) on ambiguous shape categorization with a mixed effects logistic regression in which the dependent variable was the likelihood of categorizing an ambiguous shape as round. See Fig. 2 for mean percentages of ambiguous shapes categorized as round, for

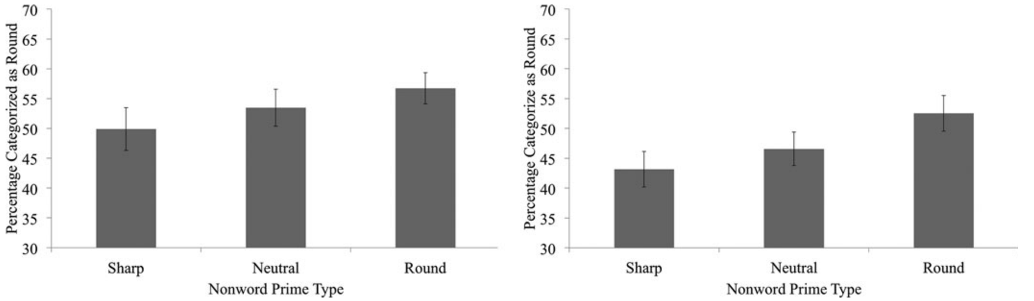

Fig. 2. The percentages of ambiguous shapes categorized as round when preceded by a sharp, neutral, or round nonword prime, in Experiment 3 (left) and 4 (right). When computing 95% CIs, the method outlined in Cousineau (2005) was used.

Table 6
Summary of logistic regression predicting the likelihood of a neutral shape being categorized as round, in Experiment 3

Fixed Effect	Coefficient	*SE*	Wald *Z*	*p*
Intercept	0.01	0.17	0.07	.94
Nonword type	0.32	0.10	3.07	.002**
Random effect		s^2		
Subject intercept		0.87		

Note. N = 1,728; log likelihood = −1,098.47; AIC = 2,202.94.
**p < .01.

round, neutral, and sharp nonword primes.[11] Nonword type was dummy coded such that sharp nonwords were treated as a reference category. Results indicated that participants were 1.38 times more likely to categorize an ambiguous shape as round when primed with a round nonword than a sharp nonword (Wald Z = 3.07, p = .002)[12]; see Table 6.

We conducted a supplementary analysis to more carefully examine the degree to which this effect could be considered implicit. Based on debriefing questionnaire responses, we removed participants who reported awareness of the experiment's hypothesis. To meet this criterion, participants had to have described the experiment's hypothesis as being that reading round or sharp nonwords would make them more likely to categorize ambiguous shapes as either round or sharp, respectively. Four participants met this criterion. After removing these participants, results indicated that participants were 1.37 times more likely to categorize an ambiguous shape as round when primed with a round nonword than a sharp nonword (Wald Z = 2.84, p = .005).

The results of this experiment suggest that responses to ambiguous shape stimuli can be influenced by the sound symbolic properties of nonword primes. Participants were more likely to categorize an ambiguous shape as round after being primed by a round nonword than a sharp nonword. Notably, this effect was also observed after removing participants who reported awareness of the experiment's purpose. These results provide some evidence of an implicit association between phonemes and roundness/sharpness. It may be that reading a nonword activated sound symbolically related shape information, which then impacted responses to ambiguous shapes. We will explore potential mechanisms for this effect in the Discussion.

Next, we investigated an alternate explanation for these results, which is that they could be an instance of *visual* priming. As is often brought up in critiques of the Maluma/Takete effect (see Nielsen & Rendall, 2011, for a review), round nonwords contain a greater proportion of orthographically round letters than do sharp nonwords. Conversely, sharp nonwords contain a greater proportion of orthographically sharp letters than do round nonwords. In fact, there is evidence that orthography can play a larger role than phonology in some instances of the Maluma/Takete effect (Cuskley et al., 2015). Thus, one could argue that the priming effects observed here are simply due to the visual appearance of the nonword primes. In Experiment 4 we assessed this alternate explanation.

6. Experiment 4

The purpose of Experiment 4 was to test whether the phonological (i.e., sound symbolic) properties of the nonwords are important to the priming effects observed for ambiguous shapes in Experiment 3. As such, Experiment 4 was a replication of Experiment 3 using auditory rather than visual presentation of nonword primes.

6.1. Method

6.1.1. Participants

Participants were 33 undergraduate students at the University of Calgary who participated in exchange for course credit.

6.1.2. Materials and procedure

The same nonword and shape stimuli were used in Experiment 4 as in Experiment 3, except that here the stimuli were presented auditorily. A professional male voice actor, naïve to the purpose of this study, created recordings of the 48 nonwords. Independent samples *t* tests indicated that there was no significant difference in mean duration between round nonword recordings ($M = 698.35$, $SD = 125.02$) and sharp nonword recordings ($M = 747.86$, $SD = 136.02$), $t(30) = 1.07$, $p = .29$; there was also no significant difference in mean maximum pitch between round nonword recordings ($M = 117.11$, $SD = 9.92$) and sharp nonword recordings ($M = 113.87$, $SD = 7.01$), $t(30) = 1.07$, $p = .29$.

As in Experiment 1, each trial began with a fixation cross for 1,000 ms. Participants were then presented with a nonword prime auditorily through a pair of headphones. The screen was blank for the duration of the prime, after which participants were immediately presented with the visual shape target to categorize. Aside from this, the procedure was identical to Experiment 3.

6.2. Results

We examined the effect of nonword prime type (sharp vs. round) with a mixed effects logistic regression in which the dependent variable was the likelihood of categorizing an ambiguous shape as round. See Fig. 2 for mean percentages of ambiguous shapes categorized as round, for round, neutral, and sharp nonword primes.[13] Nonword type was dummy coded such that sharp nonwords were treated as a reference category. Importantly, results replicated those of Experiment 3: Participants were 1.52 times more likely to categorize an ambiguous shape as round when primed with a round nonword than a sharp nonword (Wald $Z = 3.93$, $p < .001$)[14]; see Table 7.

We conducted a supplementary analysis to more carefully examine the degree to which this effect could be considered implicit. Based on debriefing questionnaire responses, we removed participants who reported awareness of the experiment's

Table 7
Summary of logistic regression predicting the likelihood of a neutral shape being categorized as round, in Experiment 4

Fixed Effect	Coefficient	*SE*	Wald *Z*	*p*
Intercept	−0.31	0.15	−2.09	.04*
Nonword type	0.42	0.11	3.93	<.001***
Random effect		s^2		
Subject intercept		0.52		

Note. N = 1,584; log likelihood = −1,033.99; AIC = 2,073.99.
$^{*}p < .05$, $^{***}p < .001$.

hypothesis. To meet this criterion, participants had to have described the experiment's hypothesis as being that hearing round or sharp nonwords would make them more likely to categorize the ambiguous shapes as either round or sharp, respectively. Three participants met this criterion. After removing these participants, results indicated that participants were 1.40 times more likely to categorize an ambiguous shape as round when primed with a round nonword than a sharp nonword (Wald Z = 3.01, p = .003).

The results of Experiment 4 clearly replicate those of Experiment 3: We again found that participants were more likely to categorize an ambiguous shape as round after a round nonword prime than a sharp nonword prime. Notably, this was observed here using auditory presentation of the nonword primes, attenuating effects of orthography. Thus, the effect cannot simply be attributed to visual priming. Of course, it is impossible to rule out the contribution of abstract grapheme knowledge, as orthography has been shown to play a role in the Maluma/Takete effect even when using auditory presentation (Cuskley et al., 2015). This effect was also observed after removing participants who reported awareness of the experiment's purpose. This shift in shape categorization following sound symbolic primes once again provides some evidence of an implicit association between phonemes and roundness/sharpness.

7. Discussion

Most demonstrations of the Maluma/Takete effect have used self-paced, explicit choice tasks in which participants are told to choose the shapes and nonwords that go together best. It was unclear whether this association exists outside of these overt tasks. While these tasks reveal correspondences between nonwords and shapes, such correspondences may be highlighted and only made relevant through the deliberation invited by the tasks. This is different than positing a more general association between nonwords and shapes, one that exists outside of tasks explicitly asking participants about it. Such an association should also influence responses on more implicit tasks. We explored this question in this study with a priming paradigm.

To begin, we ran a standard Maluma/Takete task in which participants were asked to choose between a round and a sharp shape as the best match for a nonword. Our results were consistent with the traditional Maluma/Takete effect when nonwords were read aloud (Experiment 1a) and when they were read silently (Experiment 1b). Notably, this effect was shown here to generalize over a variety of nonword and visual stimuli, and to persist when examined over 40 trials. Using this standard version of the task as a starting point, we then created a priming task in which participants were first presented with round or sharp nonword primes, and then shown round or sharp shapes to categorize (Experiment 2). We found that shape categorizations were more accurate following a congruent nonword than an incongruent one (e.g., more likely to correctly categorize a round shape after seeing *maluma* than *takete*), even after removing participants who reported being aware of the experiment's purpose. However, this priming effect was modest, and it did not emerge in response times.

The results of Experiment 2 suggest that sound symbolic priming—if it does exist—is not a robust phenomenon. It is clearly not observable under all conditions; detecting it may require more sensitive measures than those employed in Experiment 2. In particular, it seemed that categorizing clearly round or sharp shape stimuli was a very easy task. Response accuracy was near ceiling and reaction times were rapid. This may have reduced the ability to detect the effect of nonword primes. Indeed, it has been suggested that sound symbolic effects may be relatively slow to develop (e.g., Westbury, 2005, suggested that this may take longer than the time required to process a word).

In Experiments 3 and 4 we increased categorization difficulty by asking participants to categorize ambiguous shape stimuli that were somewhat round *and* sharp. That is, we examined whether processing round or sharp nonword primes would increase the chances of ambiguous shape stimuli being categorized as round or sharp, respectively. We expected these trials to be more difficult than those involving categorization of clearly round or sharp shapes, and thus reaction times would be slower. We reasoned that the slower response times, and lack of unambiguously correct answers, could make the categorization of ambiguous shapes more sensitive to sound symbolic priming effects. Nonword primes were presented visually in Experiment 3, and auditorily in Experiment 4, to test the role of prime orthography in the effect. In both experiments participants were more likely to categorize an ambiguous shape as round after being primed with a round nonword than a sharp nonword.

The results of Experiments 3 and 4 provide evidence of a more general association between certain phonemes and roundness/sharpness. Even though participants were not asked to seek out an association between nonwords and shapes, and were not told to consider the nonwords as potential labels for the shapes, a sound symbolic priming effect was observed. In addition, the effect persisted even after removing the few participants who reported being aware of the experiments' hypothesis. The fact that these experiments utilized mostly ambiguous shapes may have helped obscure their purpose, and lead participants away from explicitly considering the congruency between nonwords and shapes. It is important to note, however, that participants were only 1.38 (Experiment 3) and 1.50 (Experiment 4) times more likely to categorize an ambiguous shape as round following a round nonword prime than a sharp nonword prime. Although modest, these results provide further evidence that the Maluma/Takete effect will influence behavior on a relatively implicit task (e.g., Parise & Spence, 2012; Westbury, 2005). Notably these experiments used sequential presentation of stimuli, without telling participants of any relationship between the nonwords and shapes (cf. Kovic et al., 2010) and using a variety of stimuli (cf. Parise & Spence, 2012). This latter point is important as it suggests that the Maluma/Takete effect is not restricted to a few specific, carefully chosen stimuli (see Nielsen & Rendall, 2013, for a discussion of this argument). Instead, it appears to be broader, pertaining to groups of similar phonemes.

While nonwords were not sound symbolically related to the ambiguous shapes per se, the nonwords' relationship with roundness/sharpness impacted responses to these ambiguous shapes. This may suggest that shape–sound symbolism has a somewhat broader scope than has been previously demonstrated. One interpretation of these results is that certain features of the nonwords (i.e., their sound and articulation; recall that the role of orthography was minimized in Experiment 4, cf. Cuskley et al., 2015) are associated with particular visual features by way of a crossmodal correspondence. Whether this correspondence is borne out of a sort of synesthetic congruence (Ramachandran & Hubbard, 2001) or a co-occurrence of these features in the world (Spence, 2011), our results could suggest that reading or hearing a nonword activated associated visual information, and this affected subsequent responses to ambiguous shapes. That is, reading or hearing a nonword like *maluma* led to some activation of the feature roundness, which in turn affected the categorization of an ambiguous shape. This interpretation lends further support to an association between phonemes and shapes existing outside of tasks that invite participants to deliberately seek out correspondences between the two. The fact that these features come from different modalities may suggest that they are tapping into a multimodal semantic representation, consistent with a grounded framework for conceptual knowledge (e.g., Barsalou, 2008). It is also possible, however, that these modality-specific features activate, and are associated by way of, an amodal semantic representation (e.g., Mahon, 2015). Thus, our findings cannot adjudicate between models of semantic representation. In addition, as mentioned, it is not possible to also rule out the contribution of orthography to the effects observed here.

To our knowledge, these results are the first that could be indicative of sequential priming of shape targets, based on sound symbolic relationships. Previous studies have demonstrated that responses to ambiguous stimuli can be affected by the congruence of stimuli presented in other modalities (Maeda, Kanai, & Shimojo, 2004; Smith, Grabowecky, & Suzuki, 2007); however, these used overlapping presentation of stimuli, and thus do not appear to be instances of the same kind of priming. The present results do not, however, allow us to determine whether nonword primes had an effect on the *perception of* versus *responses to* ambiguous shapes. The literature on crossmodal correspondences includes a number of demonstrations that these correspondences can produce genuine perceptual effects (e.g., Kitagawa & Ichihara, 2002; Maeda et al., 2004; Parise & Spence, 2009). Of particular relevance to this study, Sweeny, Guzman-Martinez, Ortega, Grabowecky, and Suzuki (2012) found that presenting participants with audio files of the sounds *woo* or *wee* exaggerated the apparent vertical or horizontal elongation of oblong shapes. One theory proposed by the authors was that auditory experience might boost activity in associated visual neurons, either directly or by way of a multisensory integration area. In a similar vein, other researchers have theorized that visual stimuli are made more salient when presented with crossmodally congruent audio stimuli (see Spence, 2011, for a review).[15] If a similar perceptual mechanism was involved in this study, then perhaps the nonwords biased participants' attention to the round or sharp features of the ambiguous stimuli. While the delay between the presentation of nonwords and shapes in Experiment 3 likely rules out perceptual effects, such effects are perhaps more likely to have played a role in Experiment 4. The possibility that nonwords have perceptual effects on round and sharp shape stimuli could be investigated in future research. For instance, in a future study participants could be presented with different versions of a given shape, ranging from round to sharp, and asked to identify the option that is most similar to the one they saw on the previous trial. If nonword primes have an effect on the *perceptions* of shape stimuli, participants may report having seen a slightly rounder (sharper) shape following a round (sharp) prime.

Another possibility is that the effects observed in Experiments 3 and 4 operated at the level of response selection. As theorized by Marks, Ben-Artzi, and Lakatos (2003), responses to stimuli may be biased by the presentation of congruent or incongruent stimuli in another modality, by lowering or increasing the criterion for responding, respectively. Although Marks et al. (2003) were referring to instances in which stimuli were presented simultaneously, this explanation might be relevant to the present results. Because nonword primes were sound symbolically related to the response categories, they may have biased responding toward their congruent response category. This possibility should be tested in future research, to further evaluate the conclusions drawn from these experiments. In a series of studies on the crossmodal correspondence between size and pitch, Gallace and Spence (2006) assessed the extent to which their effects were decisional by having participants make a decision that was orthogonal to the categories being studied. Perhaps a similar strategy could be employed in a future study on sound symbolic priming effects.

An alternative explanation for the results of Experiments 3 and 4 is that participants may have ignored the ambiguous shape stimuli and simply responded based on the nonword primes (i.e., making a "round" response following a round nonword prime, without necessarily categorizing the shape itself as round). Such an interpretation would run counter to the inference that nonword primes affected the processing of ambiguous shape stimuli. However, there are several facts that speak against this interpretation. To begin, if participants were responding solely to the nonwords, we would expect accuracy to be very low on *incongruent* trials (e.g., when a round nonword preceded an unambiguously sharp shape). However, accuracy was very high on these trials in Experiment 3 (M = 94.10, SD = 17.55) and in Experiment 4 (M = 98.11, SD = 4.55). This suggests that participants did attend to shapes (and not just nonwords) in making their categorizations. Of course, it is possible that participants used a different process on trials involving ambiguous shapes. However, on these trials, participants made far fewer congruent responses than we would expect had they been responding to the nonwords alone. Recall that the nonwords were chosen specifically because they were paired with congruent shapes at a high rate during pilot testing (M = 94.15, SD = 4.37). However, this rate was much lower when these same nonwords preceded ambiguous shapes, in both Experiment 3 (M = 53.35, SD = 6.76; t(31) = 36.09, p < .001, Cohen's d = 6.72) and Experiment 4 (M = 54.70, SD = 7.03; t(31) = 26.95, p < .001, Cohen's d = 6.92). This further suggests that the shape stimuli were given consideration in participants' categorization decisions, even on trials involving ambiguous shapes.

In addition, participants were significantly slower on trials involving ambiguous shapes than on trials involving nonambiguous shapes, in Experiment 3 (M = 872.35, SD = 240.01 vs. M = 588.88, SD = 127.35; t(35) = 8.50, p < .001, Cohen's d = 1.54) and in Experiment 4 (M = 850.08, SD = 249.79 vs. M = 563.34, SD = 94.13; t(32) = 8.34, p < .001, Cohen's d = 1.67). That is, participants required more time to categorize ambiguous shapes, presumably because there was no obviously correct answer. The fact that they were slower for ambiguous shapes thus further suggests that they attended to the shapes in making their categorization responses. Lastly, if participants simply ignored the ambiguous shapes, then categorization responses should depend only on the nonword prime; we would not expect any systematic differences in the ways that particular shape items were categorized. However, there was a large range in how often particular ambiguous shapes were categorized as round in Experiment 3 (31.11–65.96; SD = 10.12) and in Experiment 4 (26.09–74.00; SD = 11.12). Moreover, there was a correlation between how often a particular ambiguous shape was categorized as round in each experiment (r = .53, p = .001). This suggests that while these shapes were all ambiguous, they each had certain features that made them slightly more visually round or sharp, and that this impacted participants' decisions in quite systematic ways. All of these facts suggest that participants did actively categorize the ambiguous shapes as round or sharp, ruling out the interpretation that responses were based only on the nonword primes.

Nevertheless, it is clear that understanding the underlying mechanism at work in the effects reported here requires further study. In addition, we do not wish to overstate the effect that *was* observed. When using only clearly round and sharp shapes in Experiment 2, only a modest priming effect was observed in response accuracy. Although a priming effect was observed in categorization responses in Experiments 3 and 4, it was again a modest effect and involved categorization of ambiguous shapes. It seems likely that while nonword primes can sound symbolically affect responses to visual stimuli, this is not a robust phenomenon. This fact has important implications for our understanding of sound symbolism. The Maluma/Takete effect is often overwhelmingly strong on explicit choice tasks—indeed, participants were 9.78 and 10.62 times more likely to make a congruent pairing than an incongruent one in the Experiments 1a and 1b. Thus, while the correspondence between nonwords and shapes can emerge as an association on implicit tasks, its effects are likely enhanced through deliberation and explicit forced choice paradigms.

These results compliment a growing literature on the role of iconicity (and nonarbitrariness) in language. For instance, ideophones (e.g., *goro*) enrich communication by conveying sensory details of the event being described (Dingemanse et al., 2015). This happens in real time, without requiring an opportunity for speakers to consider correspondences between form and meaning. This automatic evocation of sensory information is consistent with our interpretation of the results of Experiments 3 and 4. Recent work on iconicity also presents interesting future research questions regarding the explicit versus implicit nature of sound symbolic relationships. There is recent evidence that some forms of sound symbolism may be universal, whereas others are language specific, with age as a potential moderator (Kantartzis, Imai, & Kita, unpublished data; Saji, Akita, Imai, Kantartzis, & Kita, 2013). Investigating if these two forms of sound symbolism differ in their effects on implicit tasks would be an informative contribution. Another potentially relevant factor is C.S. Peirce's distinction between imagic iconicity (in which a signifier directly resembles the referent) and diagrammatic iconicity (in which the relationship between the forms of two signifiers resembles the relationship between two referents; reviewed in Jakobson, 1965). One might expect instances of imagic iconicity to emerge more readily in implicit tasks.

On the whole, these experiments demonstrate that under some circumstances, the Maluma/Takete effect is detectable using relatively implicit measures and can affect responses to stimuli that are not clearly round or sharp. This lends support to the claim that there is a general association between certain phonemes and meaning, and adds to our growing understanding of iconicity in language.

Acknowledgments

The authors thank Amanda Fernandez, Ellen Lloyd, and Morgan Teskey for their help with data collection, and Bryan van Delft for recording the audio stimuli. We also thank Dr. Suzanne Curtin for her helpful comments on an earlier draft of this manuscript. This research was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) through a postgraduate scholarship to DMS and a Discovery Grant to PMP; and by Alberta Innovates: Health Solutions (AIHS) through a graduate scholarship to DMS.

Notes

1. The term *phoneme* is used here and throughout to refer to both the category of sound (i.e., *phoneme* proper) and the actual instance of the phoneme being uttered (i.e., as opposed to the more precise term *phone*).
2. Of course ideophones also convey their meaning through morphology (see Dingemanse, 2012, for a review).
3. Köhler (1929) used the nonwords *baluma* and *takete* in this seminal work; the nonword *maluma* was introduced in the second edition (1947).
4. Westbury (2005) provided evidence of the reverse: that the visual features of shape stimuli can affect the processing of subsequently presented nonword stimuli.

5. Note, however, that the consonant phoneme /w/, classified here as “round,” has not been used as such in previous studies. Nevertheless, given that it is a sonorant consonant that is articulated with rounded lips, it seemed appropriate to include it as a “round” consonant phoneme.
6. All subsequent models initially included random subject and item intercepts as well. However, unless otherwise noted, the random item intercept was removed because its variance was equal to 0.00.
7. This model was compared to one also including nonword length and nonword length × nonword type as predictors, however, a chi-square test revealed that this did not significantly improve model fit, $\chi^2(2) = 0.26$, $p = .88$. In addition, this model was also compared to one including half (first vs. second half of trials) and half × nonword type as predictors; however, a chi-square test revealed that this did not significantly improve model fit, $\chi^2(2) = 3.39$, $p = .18$.
8. Including nonword length and nonword length × nonword type as predictors did not significantly improve model fit, $\chi^2(2) = 0.92$, $p = .63$; nor did including half and half × nonword type, $\chi^2(2) = 3.56$, $p = .17$.
9. Including nonword length and nonword length × nonword congruency as predictors did not significantly improve model fit, $\chi^2(2) = 1.93$, $p = .38$; or did including half and half × nonword congruency, $\chi^2(2) = 3.47$, $p = .18$.
10. An additional six participants guessed that nonwords were expected to affect response times to shapes. However, because they did not specifically mention round or sharp nonwords impacting responses to round or sharp shapes, respectively, they were not considered aware of the experiment’s hypothesis.
11. Although sharp, neutral, and round nonwords are not equally spaced levels of a factor, a linear trend analysis was conducted. We tested for a linear trend among levels of nonword prime type (sharp, neutral, and round) using a mixed effects logistic regression in which the dependent variable was the likelihood of categorizing an ambiguous shape as round. This analysis showed a significant positive linear trend among levels of nonword prime type (Wald $Z = 3.09$, $p = .002$).
12. Including nonword length and nonword length × nonword type as predictors did not significantly improve model fit, $\chi^2(2) = 0.07$, $p = .97$; or did including half and half × nonword type, $\chi^2(2) = 1.26$, $p = .53$.
13. As in Experiment 3, a linear trend analysis was conducted. We tested for a linear trend among levels of nonword prime type (sharp, neutral, and round) using a mixed effects logistic regression in which the dependent variable was the likelihood of categorizing an ambiguous shape as round. This analysis showed a significant positive linear trend among levels of nonword prime type (Wald $Z = 3.91$, $p < .001$).
14. Including nonword duration and nonword duration × nonword type as predictors resulted in a model that failed to converge; including half and half × nonword type did not significantly improve model fit, $\chi^2(2) = 5.07$, $p = .08$.

15. We must be cautious, however, because this was in reference to studies in which auditory and visual stimuli were presented simultaneously.

References

Alario, F. X., Segui, J., & Ferrand, L. (2000). Semantic and associative priming in picture naming. *The Quarterly Journal of Experimental Psychology: Section A*, *53*(3), 741–764.

Asano, M., Imai, M., Kita, S., Kitajo, K., Okada, H., & Thierry, G. (2015). Sound symbolism scaffolds language development in preverbal infants. *Cortex*, *63*, 196–205.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*, 617–645.

Bergen, B. K. (2004). The psychological reality of phonaesthemes. *Language*, *80*, 290–311.

Bremner, A. J., Caparos, S., Davidoff, J., de Fockert, J., Linnell, K. J., & Spence, C. (2013). “Bouba” and “Kiki” in Namibia? A remote culture make similar shape– sound matches, but different shape–taste matches to Westerners. *Cognition*, *126*, 165–172.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, *82*, 407–428.

Cousineau, D. (2005). Confidence intervals in within-subject designs: A simpler solution to Loftus and Masson’s method. *Tutorials in Quantitative Methods for Psychology*, *1*, 42–45.

Cuskley, C., Simner, J., & Kirby, S. (2015). Phonological and orthographic influences in the bouba–kiki effect. *Psychological Research*. doi:10.1007/s00426-015-0709-2

Davis, R. (1961). The fitness of names to drawings: A cross-cultural study in Tanganyika. *British Journal of Psychology*, *52*, 259–268.

Dingemanse, M. (2012). Advances in the Cross-Linguistic Study of Ideophones. *Linguistics and Language Compass*, *6*, 654–672.

Dingemanse, M., Blasi, D. E., Lupyan, G., Christiansen, M. H., & Monaghan, P. (2015). Arbitrariness, iconicity, and systematicity in language. *Trends in Cognitive Sciences*, *19*, 603–615.

Easton, R. D., Greene, A. J., & Srinivas, K. (1997). Transfer between vision and haptics: Memory for 2-D patterns and 3-D objects. *Psychonomic Bulletin & Review*, *4*, 403–410.

Flumini, A., Ranzini, M., & Borghi, A. M. (2014). Nomina sunt consequentia rerum–Sound–shape correspondences with every-day objects figures. *Journal of Memory and Language*, *76*, 47–60.

Fort, M., Weiß, A., Martin, A., & Peperkamp, S. (2013). Looking for the bouba-kiki effect in pre-lexical infants. Poster presented at the International Child Phonology Conference, Nijmegen, the Netherlands, June.

Gallace, A., Boschin, E., & Spence, C. (2011). On the taste of “Bouba” and “Kiki”: An exploration of word–food associations in neurologically normal participants. *Cognitive Neuroscience*, *2*, 34–46.

Gallace, A., & Spence, C. (2006). Multisensory synesthetic inter- actions in the speeded classification of visual size. Perception & Psychophysics, *68*, 1191–1203.

Grainger, J., & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language*, *35*, 623–647.

Hockett, C. (1963). The problem of universals in language. In J. Greenberg (Ed.), *Universals of language* (pp. 1–22). Cambridge, MA: MIT Press.

Hutchison, K. A. (2003). Is semantic priming due to association strength or feature overlap? A microanalytic review. *Psychonomic Bulletin & Review*, *10*, 785–813.

Imai, M., & Kita, S. (2014). The sound symbolism bootstrapping hypothesis for language acquisition and language evolution. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *369*, 20130298. doi:10.1098/rstb.2013.0298

Imai, M., Miyazaki, M., Yeung, H. H., Hidaka, S., Kantartzis, K., Okada, H., & Kita, S. (2015). Sound symbolism facilitates word learning in 14-month-olds. *PLoS ONE*, *10*, e0116494. doi:10.1371/journal.pone.0116494

Iwasaki, N., Vinson, D. P., & Vigliocco, G. (2007). What do English speakers know about gera-gera and yota-yota? A cross-linguistic investigation of mimetic words for laughing and walking. *Japanese-Language Education around the Globe*, *17*, 53–78.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language*, *59*, 434–446.

Jakobson, R. (1965). Quest for the essence of language. *Diogenes*, *13*, 21–37

Kitagawa, N., & Ichihara, S. (2002). Hearing visual motion in depth. *Nature*, *416*, 172–174.

Köhler, W. (1929). *Gestalt psychology*. New York: Liveright.

Köhler, W. (1947). *Gestalt psychology* (2nd ed.). New York: Liveright.

Kovic, V., Plunkett, K., & Westermann, G. (2010). The shape of words in the brain. *Cognition*, *114*, 19–28.

Lockwood, G., & Dingemanse, M. (2015). Iconicity in the lab: A review of behavioral, developmental, and neuroimaging research into sound-symbolism. *Frontiers in Psychology*, *6*, 1246. doi:10.3389/fpsyg.2015.01246

Lucas, M. (2000). Semantic priming without association: A meta-analytic review. *Psychonomic Bulletin & Review*, *7*, 618–630.

Maeda, F., Kanai, R., & Shimojo, S. (2004). Changing pitch induced visual motion illusion. *Current Biology*, *14*, R990–R991.

Mahon, B. Z. (2015). The burden of embodied cognition. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, *69*, 172–178.

Marks, L. E., Ben-Artzi, E., & Lakatos, S. (2003). Cross-modal interactions in auditory and visual discrimination. *International Journal of Psychophysiology*, *50*, 125–145.

Masson, M. E. (1995). A distributed memory model of semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 3–23.

Maurer, D., Pathman, T., & Mondloch, C. J. (2006). The shape of boubas: Sound–shape correspondences in toddlers and adults. *Developmental Science*, *9*, 316–322.

Monaghan, P., Christiansen, M. H., & Fitneva, S. A. (2011). The arbitrariness of the sign: Learning advantages from the structure of the vocabulary. *Journal of Experimental Psychology: General*, *140*, 325–347.

Monaghan, P., Shillcock, R. C., Christiansen, M. H., & Kirby, S. (2014). How arbitrary is language? *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *369*, 20130299. doi:10.1098/rstb.2013.0299

Nielsen, A., & Rendall, D. (2011). The sound of round: Evaluating the sound-symbolic role of consonants in the classic Takete-Maluma phenomenon. *Canadian Journal of Experimental Psychology*, *65*, 115–124.

Nielsen, A., & Rendall, D. (2013). Parsing the role of consonants versus vowels in the classic takete-maluma phenomenon. *Canadian Journal of Experimental Psychology*, *67*, 153–163.

Ozturk, O., Krehm, M., & Vouloumanos, A. (2013). Sound symbolism in infancy: Evidence for sound–shape cross-modal correspondences in 4-month-olds. *Journal of Experimental Child Psychology*, *114*, 173–186.

Parise, C. V., & Spence, C. (2009). "When birds of a feather flock together": Synesthetic correspondences modulate audiovisual integration in non-synesthetes. *PLoS ONE*, *4*, e5664.

Parise, C. V., & Spence, C. (2012). Audiovisual crossmodal correspondences and sound symbolism: A study using the implicit association test. *Experimental Brain Research*, *220*, 319–333.

Perniss, P., Thompson, R., & Vigliocco, G. (2010). Iconicity as a general property of language: Evidence from spoken and signed languages. *Frontiers in Psychology*, *1*, 227. doi:10.3389/fpsyg.2010.00227

Perniss, P., & Vigliocco, G. (2014). The bridge of iconicity: From a world of experience to the experience of language. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *369*, 20130300. doi:10.1098/rstb.2013.0300

Perry, L. K., Perlman, M., & Lupyan, G. (2015). Iconicity in English and Spanish and its relation to lexical category and age of acquisition. *PLoS ONE*, *10*, e0137147. doi:10.1371/journal.pone.0137147

Pexman, P. M., Cristi, C., & Lupker, S. J. (1999). Facilitation and interference from formally similar word primes in a naming task. *Journal of Memory and Language*, *40*, 195–229.

R Core Team (October 31, 2014). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. http://www.R-project.org/

Ramachandran, V. S., & Hubbard, E. M. (2001). Synaesthesia: A window into perception, thought and language. *Journal of Consciousness Studies*, *8*, 3–34.

Saji, N., Akita, K., Imai, M., Kantartzis, K., & Kita, S. (2013). Cross-linguistically shared and language-specific sound symbolism for motion: An exploratory data mining approach. *Proceedings of the 35th Annual Conf. of the Cognitive Science Society*, Berlin, Germany, 31 July–3 August 2013 (pp. 1253–1259).

Sidhu, D. M., & Pexman, P. M. (2015). What's in a name? The effects of sound symbolism in first names. *PLoS ONE*, *10*, e0126809. doi:10.1371/journal.pone.0126809

Sidhu, D. M., Pexman, P. M., & Saint-Aubin, J. (2016). From the Bob/Kirk effect to the Benoit/Éric effect: Testing the mechanism of name sound symbolism in two languages. *Acta Psychologica*, *169*, 88–99.

Smith, E. L., Grabowecky, M., & Suzuki, S. (2007). Auditory-visual crossmodal integration in perception of face gender. *Current Biology*, *17*, 1680–1685.

Spence, C. (2011). Crossmodal correspondences: A tutorial review. *Attention, Perception, & Psychophysics*, *73*, 971–995.

Sweeny, T. D., Guzman-Martinez, E., Ortega, L., Grabowecky, M., & Suzuki, S. (2012). Sounds exaggerate visual shape. *Cognition*, *124*, 194–200.

Taylor, I. K., & Taylor, M. M. (1962). Phonetic symbolism in four unrelated languages. *Canadian Journal of Psychology*, *16*, 344–356.

Topolinski, S., Maschmann, I. T., Pecher, D., & Winkielman, P. (2014). Oral approach–avoidance: Affective consequences of muscular articulation dynamics. *Journal of Personality and Social Psychology*, *106*, 885–896.

Van den Bussche, E., Notebaert, K., & Reynvoet, B. (2009). Masked primes can be genuinely semantically processed: A picture prime study. *Experimental Psychology*, *56*, 295–300.

Westbury, C. (2005). Implicit sound symbolism in lexical access: Evidence from an interference task. *Brain and Language*, *93*, 10–19.

Westermann, D. H. (1927). Laut, Ton und Sinn in westafrikanischen Sudansprachen. In F. Boas (Ed.), *Festschrift Meinhof* (pp. 315–328). Hamburg, Germany: L. Friederichsen.

Yorkston, E., & Menon, G. (2004). A sound idea: Phonetic effects of brand names on consumer judgments. *Journal of Consumer Research*, *31*, 43–51.

Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

Table S1. Results of neutral nonword classification during pilot testing.

Appendix A: Nonwords in Experiments 1a and 1b

Table A1
Nonwords used in Experiments 1a and 1b, along with the proportion of times participants paired each with a congruent shape

Nonword	Type	Congruent Responses in Experiment 1a	Congruent Responses in Experiment 1b
baamoo	Round	0.75	0.72
boobaa	Round	0.85	0.8
buubaa	Round	0.92	0.93
gogaa	Round	0.72	0.8
kaykee	Sharp	0.75	0.68
kuhtay	Sharp	0.73	0.8
maaboomaa	Round	0.67	0.67
maanuumaa	Round	0.82	0.85
maluma	Round	0.82	0.93
mowaa	Round	0.73	0.7
peetay	Sharp	0.67	0.52
puhkeetee	Sharp		0.7
puhtay	Sharp	0.42	0.4
takete	Sharp	0.8	0.8
taytee	Sharp	0.72	0.8
teetay	Sharp	0.75	0.73
tuhkeetee	Sharp	0.73	0.83
tuhpeetee	Sharp	0.67	0.75
waamuu	Round	0.87	0.65
waluma	Round	0.82	0.88

Appendix B: Neutral nonwords in Experiment 3

chuhee
fuuhee
fuushay
heechah
jeefah
juhfuu

Appendix C: Debriefing questionnaire

Have you heard of the Bouba/Kiki effect? If yes, please describe it. What do you think the point of the task you just completed was? What do you think the experimenter's expectations were for the task you just completed? Do you think there was a relationship between the nonwords and the shapes? If so, what do you think it was?

Appendix D: Nonwords used in Experiments 3 and 4

Round nonwords:

baabohmaa
baamohmaa
baamuubaa
bohbuu
bohbuumoh
bohmaa
maabaamuu
mohbuumoh
mohmaa
muuboh
muubohmuu
muubuubaa
muubuumoh
muumaa
muumuu
muumuuboh

Sharp nonwords:
kaytay
kaytaytuh
kayteetay
keekaytee
keekee
kuhkuhtee
taykaytee
taykeekee
taytaykuh
teekay
teekaykee
teekee
teekuh
tuhkee
tuhkeekee
tuhkeetee

Neutral nonwords:
faafay
faahaahay
fayhaahaa
fayhayhaa

fayjayjoh
fayjoh
fayjohjoh
fohjay
fohohfee
haafaahay
hohee
jaaheejee
jayjohfoh
johjayfay
juhjuu
juhjuu