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Consonants are More Important than Vowels in the Bouba-kiki Effect

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Abstract
Adult listeners systematically associate certain speech sounds with round or spiky shapes, a sound-symbolic phenomenon known as the "bouba-kiki effect." In this study, we investigate the respective influences of consonants and vowels in this phenomenon. French participants were asked to match auditorily presented pseudowords with one of two visually presented shapes, one round and one spiky. The pseudowords were created by crossing either two consonant pairs with a wide range of vowels (experiment 1 and 2) or two vowel pairs with a wide range of consonants (experiment 3). Analyses showed that consonants have a greater influence than vowels in the bouba-kiki effect. Importantly, this asymmetry cannot be due to an onset bias, as a strong consonantal influence is found both with CVCV (experiment 1) and VCV (experiment 2) stimuli. We discuss these results in terms of the differential role of consonants and vowels in speech perception.

Keywords
Bouba-kiki effect, sound-symbolism, vowels, consonants, French

1 Introduction

In natural languages, the vast majority of words show an arbitrary link between form and meaning (de Saussure, 1959). However, languages typically also contain words that are sound-symbolic (e.g., in French: Chastaing, 1958; in English: Bloomfield, 1933; in Japanese: Imai, Kita,

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Nagumo, & Okada, 2008). For instance, in the English lexicon, the onset /gl/ is often used for words with meanings that are related to "vision" and "light" (e.g., "glimmer," "glisten," "glitter," "gleam," "glow," "glint"), whereas the consonant cluster /kr/ is often associated with "noisy impact" meanings in verbs (e.g., "crash," "crack," "crunch"). While the lexicons of individual languages may contain sound-symbolic items such as the English ones above, listeners across languages are sensitive to certain *universal* sound-symbolic associations that might or might not be exploited in their native lexicon. In particular, in sound–shape matching tasks, participants systematically map certain pseudowords, such as "bouba" and "maluma" onto round shapes, and others, such as "kiki" and "takete," onto spiky ones, a phenomenon known as the bouba-kiki, or alternatively, the maluma–takete effect (adults: Köhler, 1929, 1947; Ramachandran & Hubbard, 2001; toddlers: Maurer, Pathman, & Mondloch, 2006). But why is a "bouba" more likely to be round whereas a "kiki" more probably refers to something spiky? To date, most studies either investigated these and other sound-symbolic associations across languages (Bremner et al., 2013; Imai et al., 2008; Kantartzis, Imai, & Kita, 2011; Nygaard et al., 2009), or focused on the emergence of such associations in the course of human ontological development (Fort, Weiss, Martin, & Peperkamp, 2013; Maurer et al., 2006; Ozturk, Krehm, & Vouloumanos, 2013; Peña, Mehler, & Nespor, 2011; Spector & Maurer, 2013). However, the nature of the information in the speech signal that is actually matched with the visual shape is still unclear. In other words, little is known about which specific speech sounds in pseudowords like "bouba" and "kiki" make them more likely to be associated with a round and a spiky shape, respectively, rather than the reverse. In the present study, we investigate the respective influence of consonants and vowels in the bouba-kiki effect.

Audiovisual cross-modal correspondences for *non-speech* stimuli have been found in different populations, showing links between simple physical stimulus dimensions such as loudness and brightness (e.g., adults and children: Bond & Stevens, 1969; 20- to 30-day-old infants: Lewkowicz & Turkewitz, 1980), pitch and brightness or visual lightness (e.g., human adults: Marks, 1987; chimpanzees: Ludwig, Adachi, & Matsuzawa, 2011; toddlers: Mondloch & Maurer, 2004), pitch and size (e.g., adults: Gallace & Spence, 2006), pitch and visual elevation (11-month-olds: Wagner, Winner, Cicchetti, & Gardner, 1981; three- to four-month-olds: Walker et al., 2010), pitch and visual sharpness (adults: Marks, 1987; three- to four-month-olds: Walker et al., 2010), and so on (for reviews see Marks, 2004; Spence, 2011; Walker, 2012). For instance, regarding sound–shape associations, Marks (1987, experiment 4) used a speeded classification task where participants had to determine the spikiness of visually presented stimuli. Results showed slower reaction times and higher error rates when the object was accompanied by an incongruent auditory tone (i.e., high-pitched tone + round shape, low-pitched tone + spiky shape) rather than by a congruent one (i.e., high-pitched tone + spiky shape, low-pitched tone + round shape). Several studies have also documented cross-modal correspondences between auditory speech stimuli on the one hand and different visual properties of objects on the other hand, such as size (Parise & Spence, 2012; Peña et al., 2011; Sapir, 1929), brightness (Parise & Pavani, 2011), and shape (Köhler, 1929, 1947; Kovic, Plunkett, & Westermann, 2010; Maurer et al., 2006; Monaghan, Mattock, & Walker, 2012; Nielsen & Rendall, 2011; Ozturk et al., 2013; Parise & Pavani, 2011; Parise & Spence, 2012; Ramachandran & Hubbard, 2001; Sweeny, Guzman-Martinez, Ortega, Grabowecky, & Suzuki, 2012; Westbury, 2005).

With regards to speech–shape associations, while many studies have investigated the bouba-kiki effect, only a few of them have explicitly manipulated specific auditory components in the speech material (Monaghan et al., 2012; Nielsen & Rendall, 2011; Ozturk et al., 2013; Parise & Pavani, 2011; Parise & Spence, 2012; Sweeny et al., 2012). For instance, in two different experiments, Monaghan et al. (2012) compared different types of consonants (i.e., stops vs. continuants) and vowels (i.e., close front vs. open back vowels), respectively. Using a cross-situational learning paradigm, they found that participants better learned congruent sound-symbolic pairings between pseudowords and shapes (i.e., spiky shapes paired with stop consonants or close front vowels, and round shapes paired with continuant consonants or open back vowels) rather than incongruent ones. This study indicates that both consonantal and vocalic features play a role in speech–shape correspondences. However, little is known about the *respective* roles of consonants and vowels in the bouba-kiki effect.

This sound-symbolic phenomenon has often been claimed to depend mostly on the nature of the vowels in the speech stimuli (Maurer et al., 2006; Ramachandran & Hubbard, 2001; Tarte, 1974, 1982), possibly because perceivers match the visual shape with the shape of the lips when producing the vowels of the speech stimuli (e.g., presence of lip rounding in /u/, as in "bouba" or "maluma," vs. absence of lip rounding in /i/ and /e/ as in "kiki" and "takete"). However, two recent studies found that consonants seem to play a more important role than vowels in the bouba-kiki effect. Nielsen and Rendall (2011) used a forced-choice task, where in each trial participants had to match an auditory CVCV[1] or CVCVCV pseudoword with one of two visually presented shapes, one round, one spiky. Results indicated that, regardless of the vowels, auditory pseudowords containing certain consonants, including /b/, /m/, /l/ and /ɡ/, are mapped more often onto round shapes, while pseudowords containing other consonants, including /p/, /t/ and /k/, are mapped more often onto spiky shapes. These data suggest the existence of a bias to rely more on consonants than on vowels when performing such sound-symbolic pairings. Using the same design, Ozturk et al. (2013) directly examined which type of segments (consonants, vowels, or both) are used to match the pseudowords /bubu/, /kiki/, /bibi/ and /kuku/ with round and spiky shapes. For instance, when the pseudoword /bibi/ was paired with a round shape, the choice was considered to be based on the consonant (/b/ → round), whereas when it was paired with a spiky shape, the choice was considered to be based on the vowel (/i/ → spiky). In accordance with Nielsen and Rendall (2011), the authors found more consonant-based than vowel-based responses.

These results mesh well with findings on the differential roles of vowels and consonants in speech processing. In particular, consonants have been shown to be more important for lexical access (Bonatti, Peña, Nespor, & Mehler, 2005; Caramazza, Chialant, Capasso, & Miceli, 2000; Cutler, Sebastian-Galles, Soler-Vilageliu, & van Ooijen, 2000; Mehler, Peña, Nespor, & Bonatti, 2006; Nespor, Peña, & Mehler, 2003; New & Nazzi, 2014; Toro, Nespor, Mehler, & Bonatti, 2008; Toro, Shukla, Nespor, & Endress, 2008), whereas vowels have been argued to carry more information for the purpose of syntactic processing (Nespor et al., 2003; Toro, Nespor, et al., 2008; Toro, Shukla, et al., 2008). To the extent that mapping pseudowords onto visual shapes triggers processing at a more lexical rather than a syntactic level, the greater influence of consonants than vowels reported by Nielsen and Rendall (2011) and Ozturk et al. (2013) is thus unsurprising. However, more research is needed before drawing the conclusion that consonants play a more important role than vowels in the bouba-kiki effect, for two reasons. First, both of the studies only tested a small number of stimuli: Nielsen and Rendall (2011) used five pairs of pseudowords while Ozturk et al. (2013) used only two, including a limited subset of the English phoneme inventory. Second, they used only consonant-initial pseudowords, making it impossible to rule out that the consonantal bias reflects an onset effect.

The goal of the present research is to provide further evidence regarding the respective roles of consonants and vowels in the bouba-kiki effect. First, we test a larger set of segments (nine vowels and 15 consonants) to explore the robustness of the consonant–vowel asymmetry. Second, we use both consonant- and vowel-initial stimuli to test for a possible onset bias. We report on three experiments with French adult participants, using a forced-choice association task as in Nielsen and Rendall (2011) and Ozturk et al. (2013). In experiments 1 and 2, we explore the role of vowels on the bouba-kiki effect, while in experiment 3 we focus on the influence of consonants.

2 Experiment 1

The goal of experiment 1 is to explore whether changing the identity of the vowels in the stimuli used in Köhler's (1947) original study influences the sound-symbolic matching process. We constructed pseudowords with varying vowels and two fixed consonant pairs based on those of "maluma" (i.e., /l,m/) and "takete" (i.e., /t,k/). We used disyllabic instead of trisyllabic stimuli because disyllables constitute the most prevalent word form in the French lexicon. Participants were asked to match these pseudowords with one of two visually presented shapes, one round, one spiky. If they rely more on consonants than on vowels to perform the sound–shape association, they should match pseudowords containing /m/ and /l/ more often with round shapes and those containing /t/ and /k/ with spiky shapes, regardless of the vowels.

2.1. Method

2.1.1. Participants. Twenty-four native French-speakers (five men and 19 women, mean age: 26 years, range: 18–58) participated in the experiment. None of them had a known history of hearing or language impairment.

2.1.2. Material. We constructed 32 CV_iCV_i pseudowords in which the vowel varied among nine Standard French vowels (/i/, /y/, /e/, /ø/, /a/, /u/, /o/, /ɛ̃/, /ɑ̃/) and the consonants were either /l/ and /m/ (irrespective of order) or /k/ and /t/ (again, irrespective of order) (e.g., /lumu/, /mili/, /koto/, / teke/; see Appendix A for a complete list[2]). The pseudowords were recorded in a soundproof booth by a female native French-speaker. As the stimuli were also used for an infant study not reported on here, they were recorded in infant-directed speech. Stimuli were balanced across two different experimental lists (16 per list), such that for each combination of consonant pair and vowel, one pseudoword was part of list 1 and the other of list 2 (e.g., list 1 contained /lumu/ and /mɛ̃lɛ̃/, while list 2 contained /mulu/ and /lɛ̃mɛ̃/, see Appendix A).

To construct the visual stimuli, we created a set of 33 spiky and round black-outlined shapes with Adobe Photoshop CS6, and filled each of them with two different colors (yellow and orange).[3] We then asked 50 participants in a Mechanical Turk online study to judge the form of each shape on a scale from 1 (very round) to 7 (very spiky), and selected eight round and eight spiky shapes that – regardless of color – were considered overall to be roundest (scored 1–2) and spikiest (scored 6–7), respectively. The yellow and the orange versions of these shapes constituted the final set of visual stimuli, for a total of 32 shapes. Examples of a round and a spiky shape type are shown in Figure 1.

2.1.3. Procedure. Participants were randomly assigned to list 1 or list 2. They were seated at 40cm from a computer monitor in a soundproof booth, and listened to the pseudowords through headphones. For each trial, one round and one spiky shape (both either yellow- or orange-filled) appeared side-by-side on the screen, against a white background. Then, after 500ms, participants heard a pseudoword and had to press one of two labeled keys (one was on the left side and the other on the right side of the keyboard) to indicate whether they felt that the pseudoword referred to the

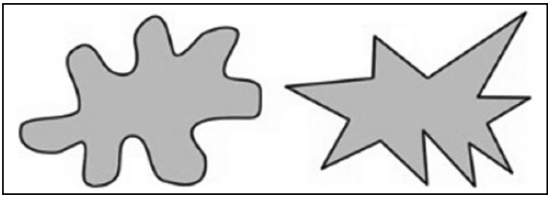

Figure 1. Example of a round and a spiky shape used in experiments 1, 2 and 3.

shape on the left or on the right, respectively. There was no time pressure on their response and they could replay the auditory stimulus as often as they wanted by pressing the "R" key. The next trial started immediately after the participant had answered.

Participants were tested on 16 trials, one for each pseudoword. For each participant, each pseudoword was randomly matched with one spiky and one round shape of the same color. Round and spiky shapes appeared an equal number of times on the left and right sides of the screen. Each colored shape was used exactly once. The order of the stimuli was randomized. The E-Prime 2.0 software (Psychological Software Tools, Pittsburgh, PA, USA) was used to generate the stimuli and to collect participants' responses.

2.2. Results and discussion

For each trial, we coded each participant's choice as "1" or "0," depending on whether it corresponded to the round or the spiky shape, respectively. These scores were then averaged between subjects for each condition. The level equivalent to chance (i.e., 50%) was subtracted from these means, showing either an overall preference for round or spiky shapes. Results for each condition are reported in Figure 2. Positive scores indicate a preference for round shapes, negative scores indicate a preference for spiky shapes. For all the analyses reported in this study, we used a logistic mixed-effects model to analyze the data with R (R Core Team, 2012) and the lme4 package (Bates, Maechler, & Bolker, 2012). Participants were a random factor, while vowel identity (/i/, /y/, /e/, /ø/, /a/, /u/, /o/, /ɛ̃/, /ɑ̃/) and consonant pair (/l,m/, /t,k/) were within-participant fixed factors. Initially, list (1, 2) was also declared as a random factor, but it did not significantly increase the variance accounted for and was thus excluded from the final model (see Appendix D). The vowel /ɑ̃/ in the condition /t,k/ was used as the intercept because it yielded a mean score that was not significantly different from the 50% chance level (M= 42 %, SD = 0.5, $t(23) < 1$).

Results revealed a significant influence of consonant pair ($\beta = 2.84$, SE = 0.88, $z = 3.28$, $p = .001$), indicating that pseudowords containing /t/ and /k/ were more often mapped onto spiky shapes whereas pseudowords containing /l/ and /m/ were more often mapped onto round shapes. For vowel identity, however, the analysis yielded no effect except a marginally significant one for /e/ ($\beta = -1.33$, SE = 0.69, $z = -1.91$, $p = .059$), showing that vowel identity did not influence the sound–shape mapping process. There was no interaction between consonant pair and vowel identity.

2.3. Discussion

The goal of this experiment was to explore whether varying the vowels influences the cross-modal correspondences observed in the classic bouba-kiki effect. The results indicate that this is not the case: regardless of the vowel, participants consistently mapped pseudowords containing /l/ and /m/

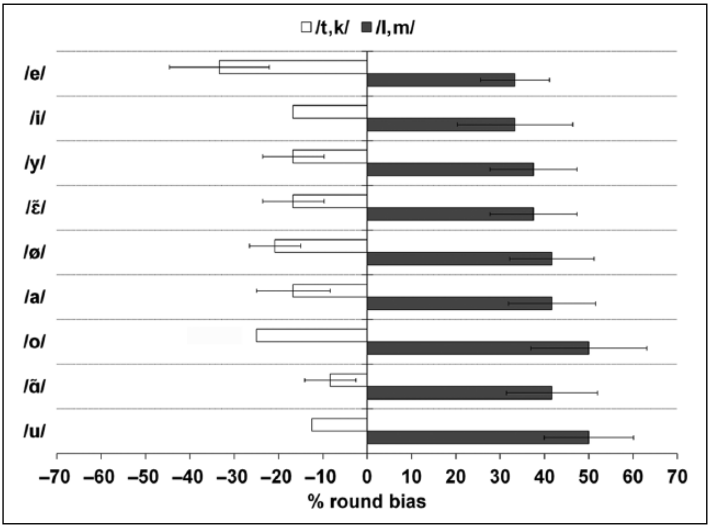

Figure 2. Percentage of bias to choose round shapes over spiky shapes (round bias) as a function of vowel identity (/u/, /ɑ̃/, /o/, /a/, /ø/, /ɛ̃/, /y/, /i/, /e/) and consonant pair (/l,m/ vs. /t,k/). The error bars represent standard error.

to round shapes and ones containing /t/ and /k/ to spiky shapes. In other words, only the consonants influenced the sound–shape mappings. By selecting a larger set of stimuli than previously used (Nielsen & Rendall, 2011; Ozturk et al., 2013) and by systematically varying the vowel and consonant pairings, we thus demonstrated a robust consonant–vowel asymmetry. Our results suggest that, in line with the findings of Nielsen and Rendall (2011) and Ozturk et al. (2013), consonants have a greater influence than vowels in the bouba-kiki effect. However, this experiment cannot rule out that an onset bias rather than a consonant bias is responsible for the pattern of results, as all the stimuli were consonant-initial. To disentangle these two possible explanations, we ran a second experiment with vowel-initial stimuli.

3 Experiment 2

In this experiment, we used the same design as in experiment 1, except that the pseudowords were of the form V_iCV_i (e.g., /ulu/, /imi/, /yky/, /ata/) instead of CV_iCV_i. Thus, our stimuli were vowel-initial, which might encourage participants to rely on vowels to perform sound–shape associations. If the effect observed in experiment 1 is due to an onset bias, we should observe a consistent influence of vowel identity regardless of the consonant pair.

3.1. Method

3.1.1. Participants. Twenty-four native French-speakers (eight men and 16 women, mean age: 21.9 years, range: 19–28) participated in the experiment. None of them had a known history of hearing or language impairment and none had participated in experiment 1.

3.1.2. Material. As in experiment 1, we constructed 32 V_iCV_i pseudowords in which the vowel varied among nine Standard French vowels (/i/, /y/, /e/, /ø/, /a/, /u/, /o/, /ɛ̃/, /ɑ̃/) and the consonants

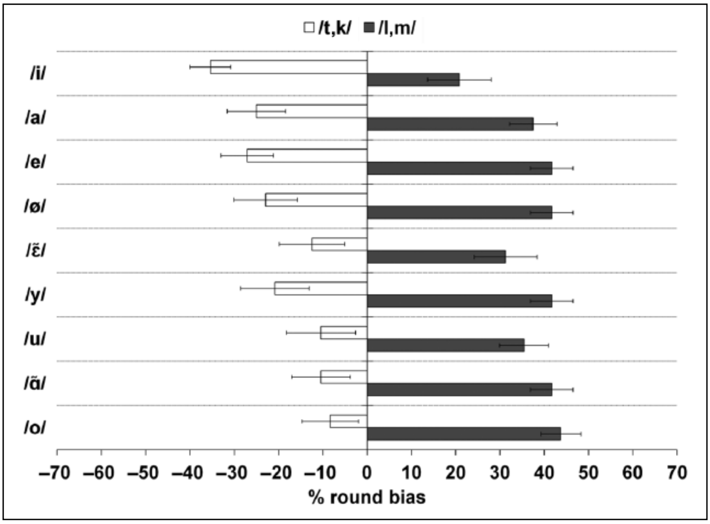

Figure 3. Percentage of bias to choose round shapes over spiky shapes (round bias) as a function of vowel identity (/u/, /ɑ̃/, /o/, /a/, /ø/, /ɛ̃/, /y/, /i/, /e/) and consonant pair (/l,m/ vs. /t,k/). The error bars represent standard error.

were either /l/, /m/, /k/ or /t/ (e.g., /olo/, /imi/, /eke/, /ata/; see Appendix B for a complete list). The stimulus preparation and recording procedure were the same as in experiment 1, except that the speaker was told to produce the stimuli in adult-directed speech. For the visual stimuli, we created one round and one spiky shape and added them to the eight original round and spiky shapes used in experiment 1. As in experiment 1, we filled them with two different colors (yellow and orange) and then mirrored them either horizontally or vertically to increase the number of each shape type to 36 (e.g., 9 pairs of shapes × 2 colors × 2 mirror-image versions).

3.1.3. Procedure. The procedure was the same as in experiment 1 except that each participant was presented with all the pseudowords.

3.2. Results

The coding procedure for the participants' responses was the same as in experiment 1. Results for each condition are reported in Figure 3. As in experiment 1, positive scores indicate a preference for round shapes and negative scores a preference for spiky shapes. As in experiment 1, we analyzed the data using a logistic mixed-effects model with participants as a random factor and vowel identity (/i/, /y/, /e/, /ø/, /a/, /u/, /o/, /ɛ̃/, /ɑ̃/) and consonant pair (/l,m/, /t,k/) as within-participants fixed factors (see Appendix E for further details about the final model). The vowel /ɑ̃/ in the condition /t,k/ was used as intercept because it yielded a mean score that was not significantly different from the 50 % chance level (M= 40 %, SD = 0.5, $t(47) = -1.46$, $p = .15$).

The results revealed a significant effect of consonant pair ($\beta = 2.88$, SE = 0.61, $z = 4.74$, $p < .001$). A main effect of vowel identity was significant, indicating the pseudowords containing /i/ were significantly more often associated with a spiky shape than those containing /ɑ̃/ ($\beta = -1.37$, SE = 0.51, $z = -2.69$, $p < .01$). A similar, marginally significant, tendency was observed for /e/ ($\beta = -0.81$, SE = 0.46, $z = -1.77$, $p = .08$). There was no interaction between consonant pair and vowel identity.

3.3. Discussion

In this experiment, we tested whether the consonant–vowel asymmetry observed in experiment 1 could be due to an onset bias, by using V_iCV_i instead of CV_iCV_i stimuli. The results showed that overall, pseudowords with /k/ and /t/ were more often associated with spiky shapes than those with /l/ and /m/. The magnitude of this effect was similar to the one observed in experiment 1 (experiment 1: $\beta = 2.84$; experiment 2: $\beta = 2.88$). Moreover, there was only a small influence of the vowels: /i/ and /e/ were more often associated with spiky shapes than the other vowels (/y/, /ø/, /a/, /u/, /o/, /ɛ̃/ and /ɑ̃/). These effects were small (/i/: $\beta = -1.37$, /e/: $\beta = -0.81$) and significant only for /i/. Thus, despite the fact that the pseudowords were vowel-initial, participants relied mostly on the consonantal information. This, then, shows that the consonant–vowel asymmetry observed in experiment 1 cannot be due to the fact that the pseudowords in that experiment were consonant-initial.

One caveat is still in order, though. As participants had to make a two-alternative forced choice in both experiment 1 and 2, they might have developed a response strategy to focus on the consonants rather than on the vowels, because there were likewise two pairs of consonants but many different vowels. If the consonant–vowel asymmetry is due to such a response strategy, we should observe the reverse asymmetry when using two vowel pairs and multiple consonants. Conversely, if this strategy is not the main factor that induced this pattern of results, we should still observe a consonant–vowel asymmetry, at least for the consonants used in experiments 1 and 2 (i.e., /l/, /m/, /t/ and /k/). In the next experiment, we thus use the same paradigm as in experiments 1 and 2, but with stimuli that exhibit a wide range of consonants and only two pairs of vowels. This experiment will also allow us to gain insight into which consonants besides /l/ and /m/ tend to be associated with round shapes, and which ones beside /t/ and /k/ are more often associated with spiky shapes. For instance, Monaghan et al. (2012) found that the association of individual consonants with round or spiky shapes by English listeners depends on the feature continuancy, with sonorants and fricatives being associated with the former and stops with the latter. If continuancy is likewise the determining feature for French listeners, we expect to observe the same response pattern.

4 Experiment 3

In this experiment, we constructed C_iVC_iV stimuli by crossing 15 different consonants with two pairs of vowels (/o,u/ and /i,e/) that are typically mapped to round and spiky shapes, respectively (Maurer et al., 2006; Monaghan & Mattock, 2012; Ramachandran & Hubbard, 2001; Tarte, 1974, 1982).

4.1. Method

4.1.1. Participants. Twenty-three native French-speakers (nine men and 14 women, mean age: 26 years, range: 21–40) participated in the experiment. None of them had a known history of hearing or language impairment, and none had participated in experiment 1 or 2.

4.1.2. Material. We created 56 C_iVC_iV pseudowords in which the consonant varied among 15 Standard French consonants (six stops: /p/, /b/, /t/, /d/, /k/, /g/ and nine continuants: /f/, /v/, /s/, /z/, /ʃ/, /ʒ/, /l/, /m/, /n/) and the vowels were either /o/ and /u/ (irrespective or order) or /i/ and /e/ (again, irrespective of order) (e.g., /pupo/, /popu/, /kike/, /keki/; see Appendix C for a complete list[4]). The pseudowords were recorded by a female native French-speaker. As the stimuli were also used for an infant study not reported on here, they were recorded in infant-directed speech. As in

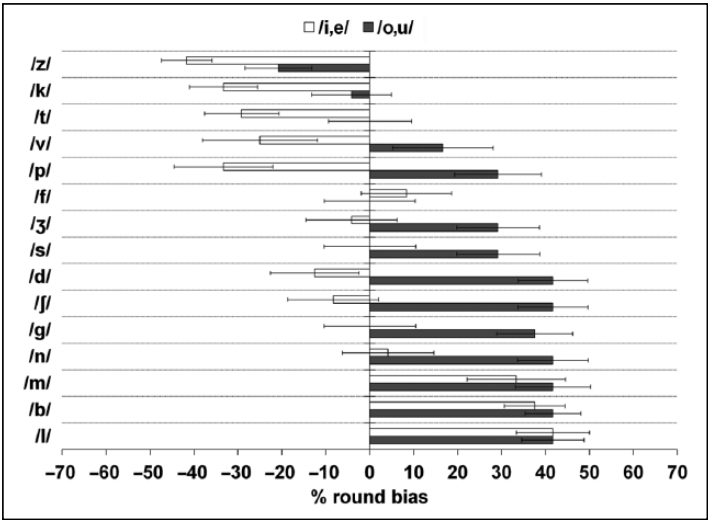

Figure 4. Percentage of bias to choose round shapes over spiky shapes (round bias) as a function of consonant identity (/l/, /b/, /m/, /n/, /g/, /ʃ/, /d/, /s/, /ʒ/, /f/, /p/, /v/, /t/, /k/, /z/) and vowel pair (/o,u/ vs. /i,e/). The error bars represent standard error.

experiment 1, stimuli were balanced across two different experimental lists (28 per list), such that for each combination of vowel pair and consonant, one pseudoword was part of list 1 and the other of list 2 (e.g., list 1 contained /popu/ and /fufo/, while list 2 contained /pupo/ and /fofu/, see Appendix C). To construct the visual stimuli we randomly selected 14 round and spiky shapes from experiment 1. As in experiment 1, we filled them with two different colors, to increase their number to 28 for each shape type.

4.1.3. Procedure. The procedure was the same as in experiment 1.

4.2. Results

Scoring of participants' responses was done in the same way as in the previous two experiments. Results for each condition are reported in Figure 4. Positive scores indicate a preference for round shapes and negative scores indicate a preference for spiky shapes. As in experiments 1 and 2, we analyzed the data using a logistic mixed-effects model with participants as a random factor and consonant identity (/p/, /b/, /t/, /d/, /k/, /g/, /f/, /v/, /s/, /z/, /ʃ/, /ʒ/, /l/, /m/, /n/) and vowel pair (/o,u/, /i,e/) as within-participants fixed factors. Initially, list (1, 2) was also declared as random factor, but it did not significantly increase the variance accounted for and was hence excluded from the final model (see Appendix F). The consonant /f/ in the condition /o,u/ was used as intercept because it yielded mean scores that were not significantly different from the 50% chance level (M= 50 %, SD = 0.51, $t(23) < 1$).

Results revealed a main effect of consonant identity, such that pseudowords containing the consonants /b/, /ʃ/, /d/, /l/, /m/, /n/ (all $\beta = 2.43$, all SE = 0.85, all $z = 2.85$, all $p < .005$), /s/, /p/, /ʒ/ (all $\beta = 1.36$, all SE = 0.65, all $z = 2.09$, all $p < .05$), and /g/ ($\beta = 1.98$, SE = 0.745, $z = 2.65$, $p < .01$) were significantly more often associated with round shapes than those containing /f/. Pseudowords containing the remaining consonants (/k/ and /t/: both $z < 1$; /v/: $\beta = 0.7$, SE = 0.58, $z = -1.18$ $p =$

.23; /z/: /$\beta = -0.9$, SE = 0.6, $z = -1.5$ $p = .14$) did not significantly differ from those containing /f/. The main effect of vowel pair was not significant ($z < 1$). However, there was an interaction between consonant identity and vowel pair: the effect of vowel pair was significant for some consonants (/ʃ/: $\beta = -3.12$, SE = 1.03, $z = -3.014$ $p < .005$; /d/: $\beta = -3.3$, SE = 1.04, $z = -3.18$, $p < .005$; /g/: $\beta = -2.32$, SE = 0.95, $z = -2.45$ $p < .05$; /ʒ/: $\beta = -1.87$, SE = 0.88, $z = -2.14$, $p < .05$; /k/: $\beta = -1.81$, SE = 0.90, $z = -2.01$ $p < .05$; /n/: $\beta = -2.6$, SE = 0.1, $z = -2.52$ $p < .05$; /p/: $\beta = -3.4$, SE = 1.1, $z = -3.08$, $p < .005$). For the remaining consonants, the effect of vowel pair was either marginally significant (/s/ and /t/: both $\beta = -1.17$, both SE = 0.87, both $z = -1.95$, both $p = .052$; /z/: $\beta = -1.87$, SE = 1.05, $z = -1.78$ $p = .08$), or not significant (/m/, /l/ and /b/: all $z < 1$).

4.3. Discussion

In this experiment we further investigated the consonant bias observed in experiments 1 and 2 by testing a wider range of consonants, combined with two vowel pairs traditionally thought to be associated with round and spiky shapes, respectively. First, we did not observe any significant main effect of vowel pair. Regarding the main effect of consonant identity, we found that /b/, /ʃ/, /d/, /l/, /m/, /n/, /s/, /p/, /ʒ/ and /g/ were more often associated to round shapes than /f/, /k/, /t/, /v/ and /z/. Finally, interactions between consonant identity and vowel pair indicated that vowel pair had a significant influence in the context of most of the consonants, within the same range as that of consonant identity ($1.8 \leq \beta \leq 3.5$), indicating that /i/ and /e/ were more often associated with spiky shapes than /o/ and /u/, except in the context of /t/, /s/ and /z/ (where the effect was marginally significant) and /b/, /m/ and /l/ (where the effect was not significant).

These results indicate, first of all, that the consonant–vowel asymmetry observed in experiments 1 and 2 is likely not due to a response strategy according to which listeners favored consonants because they came in two pairs, thus matching the number of proposed alternatives in the forced-choice task. Indeed, according to this hypothesis we should have observed a reversed vowel–consonant asymmetry in the present experiment, contrary to fact. Second, this data shows that consonants are not associated with round and spiky shapes according to their continuancy feature. Recall that Monaghan et al. (2012) found that English listeners tend to associate sonorants and fricatives with round shapes and stops with spiky shapes. The present experiment shows a more subtle pattern of results, by unpacking the coarser distinction made in Monaghan et al. (2012). Even though most continuant consonants were more often associated with round shapes, two of them (i.e., /v/ and /z/) were more often associated with spiky shapes. Moreover, among the stop consonants, only two (i.e., /t/ and /k/) were more often associated with spiky shapes, the remaining four (i.e., /b/, /p/, /g/ and /d/) were more often associated with round shapes. Finally, the fact that we observed a significant influence of the vowel pair in items containing nine out of the 15 consonants shows that vowels do play a role, albeit a minor one, in the bouba-kiki effect.

5 General discussion

Since Köhler et al.’s (1947) original study, the bouba-kiki effect has been extensively investigated, but the exact mechanism underlying this specific sound-symbolic phenomenon remains unclear. The present study examined the respective roles of consonants and vowels in this effect. We conducted three experiments in French monolingual adults, using a forced-choice association task in which pseudowords were to be mapped to one of two shapes. In experiment 1, participants consistently mapped CVCV pseudowords containing /l/ and /m/ to round shapes and those containing /t/ and /k/ to spiky shapes, regardless of the nine different vowels with which they could be paired. Experiment 2 yielded basically the same pattern of results with VCV stimuli, ruling out the possibility that the consonant–vowel asymmetry observed in experiment 1 reflected an onset bias. In experiment 3, we used CVCV pseudowords by crossing 15 different consonants with two pairs of vowels and found that vowels do have an influence, when paired with consonants other than /m/, /l/ and /b/. Participants more often mapped pseudowords containing /o/ and /u/ to round shapes and those containing /i/ and /e/ to spiky shapes. In the following, we first discuss separately the influence of vowels and consonants, respectively, in the bouba-kiki effect. Then, we focus on the respective roles of consonants and vowels and discuss the possible implications of our findings for theories that describe different functions of consonants and vowels in speech perception.

Regarding the influence of vowels in the bouba-kiki effect, this study indicates that, as previously shown (Maurer et al., 2006; Monaghan et al., 2012; Ramachandran & Hubbard, 2001; Tarte, 1974, 1982), front unrounded vowels (e.g., /i/, /e/) are more often associated with spiky shapes, while back rounded vowels (e.g., /u/, /o/) are more often associated with round shapes. As the two types of vowels differ both in rounding and in backness, either one of these features might be responsible for the effect. On the one hand, vowel rounding is directly visible as lip protrusion and it has been argued that this is what leads to the association of round/rounded and unrounded vowels with round and spiky shapes, respectively (Maurer et al., 2006; Ramachandran & Hubbard, 2001). On the other hand, front vowels have a higher F_2 than back vowels (the two types of vowels do not greatly differ in F_1), and previous studies have shown sound-symbolic associations between high-pitched and low-pitched auditory stimuli with spiky and round shapes, respectively, in both infants and adults (Marks, 1987; Parise & Spence, 2012; Walker, 2012; Walker et al., 2010). Most languages have only front unrounded and back rounded vowels. French, however, also has front rounded vowels, and although the present study was not designed to examine this question, we did include two front rounded vowels, /y/ and /ø/, in experiments 1 and 2 (see Figures 2 and 3). Interestingly, the mean round bias (averaged across consonant type) observed for both of these vowels in both experiments 1 and 2 is comprised between the mean bias observed for /i/ and /e/ on the one hand that for /o/ and /u/ on the other hand. Thus, both rounding and backness might contribute to the bouba-kiki effect found in vowels. More research combining the three types of vowels (front rounded, front unrounded, back rounded) with consonants that yield no strong association with either round or spiky shapes (e.g., /p/ and /v/, see Figure 4) is needed to further investigate this issue.

With regards to the influence of consonants, the overall pattern of data observed in this study is more complex. One thing is clear: the consonants /m/ and /l/ stand out as “round” insofar as they were systematically associated with round shapes across all experiments. As both of these consonants are sonorants, one could hypothesize that it is this feature (or more basically their status as continuants) that leads to such consistent sound-symbolic associations (as claimed by Monaghan et al., 2012; Westbury, 2005; see also Parise & Spence, 2012, for similar distinctions). However, as previously stated, this hypothesis cannot entirely explain the pattern observed in experiment 3, in that certain fricatives (which are also continuants) were more often associated with spiky shapes and certain plosives (which are not continuants) were more often associated with round shapes. Another noticeable difference between /m/ and /l/ vs. /t/ and /k/ is that the former are voiced whereas the latter are voiceless. Interestingly, Monaghan et al. (2012) found that in the English lexicon, words referring to the concept of angularity or spikiness are more likely to contain voiceless consonants, whereas words referring to roundness are more likely to contain voiced consonants. Thus, one might raise the hypothesis that voiced consonants are associated with round shapes and voiceless ones with spiky shapes. Voiced consonants are produced with vocal fold vibration and contain more intensity in lower frequency bands; either of these characteristics might lead to the association with round shapes. Yet again, our data do not entirely support this hypothesis. The most striking counterexample is /s/, which was more often associated with round shapes:

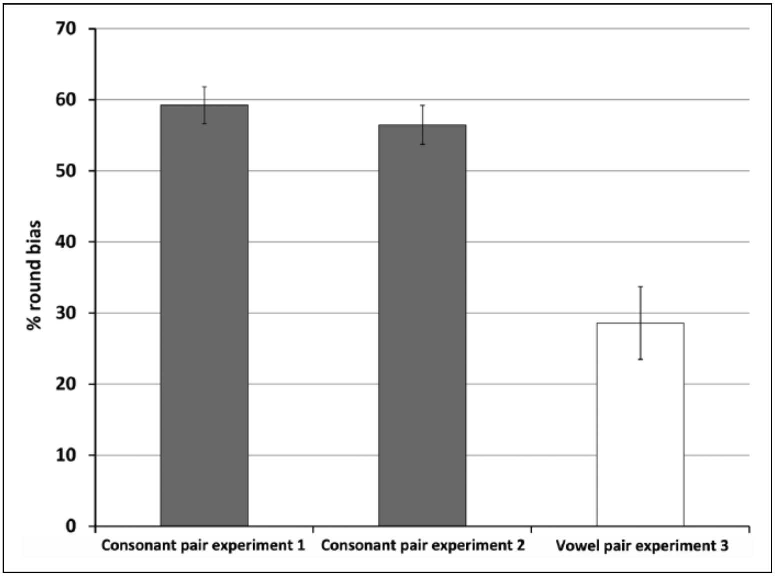

Figure 5. Effect of consonant pair in experiment 1 and experiment 2 (mean round bias for /l,m/ minus mean round bias for /t,k/) and the effect of vowel pair in experiment 3 (mean round bias for /o,u/ minus mean round bias for /i,e/). The error bars represent standard error.

not only is this consonant voiceless, it also contains the largest amount of energy in high-frequency bands among all French consonants.

Considering the respective influence of vowels and consonants in the bouba-kiki effect, this study indicates, first of all, that at least for some consonants there is little or no influence of the vowel. This result holds even with VCV pseudowords and hence cannot be attributed to an onset effect. Note also that it is independent of the type of speech in which the pseudowords had been recorded, that is, infant-directed as in experiments 1 and 3 or adult-directed as in experiment 2. As infant-directed speech is characterized, among other things, by lengthened vowels, one might expect that this type of speech encourages participants to rely on vowels, but this does not appear to be the case in the present study.

To further compare the respective influence of consonants and vowels across our three experiments, we compared the effect of consonant pair obtained in experiments 1 and 2 to the effect of vowel pair observed in experiment 3. To do so, we estimated the effect of consonant pair in experiments 1 and 2 by subtracting the mean round bias score obtained across the nine modalities of vowel identity in the /t,k/ condition from the one obtained in the /l,m/ condition. Similarly, we estimated the effect of vowel pair by subtracting the mean round bias score obtained across the 15 modalities of consonant identity in the /o,u/ condition from the one obtained in the /i,e/ condition. We then conducted a one-way ANOVA on these measures declaring effect type (consonant experiment 1, consonant experiment 2, vowel experiment 3) as a between-subject factor. Results are shown in Figure 5.

The analysis yielded a significant main effect of effect type $F(2, 30) = 15.5$, $p < .001$, $\eta^2_p = .50$. Planned comparisons revealed that it was due to the fact that the difference observed for vowel pair in experiment 3 was significantly smaller than the difference observed for consonant pair in experiments 1 and 2 $F(1, 30) = 29.96$, $p < .001$, $\eta^2_p = .97$, while the effect of consonant pair in experiments 1 and 2 did not statistically differ from one another ($F < 1$). Overall, this data indicates that the effect of consonant pair was greater than the effect of vowel pair across the three experiments. The fact that the effect of consonant pair in experiment 1 was not significantly different from the one observed in experiment 2, moreover, strengthens our claim that the consonant–vowel asymmetry in the bouba-kiki effect is not due to an onset effect. This result indeed shows that initial consonants do not contribute more to the bouba-kiki effect than non-initial ones. It also provides a statistical underpinning of the claim that infant- and adult-directed speech stimuli are not treated any differently.

Finally, the present study used a wider range of consonants and vowels than previous ones that likewise showed a consonant–vowel asymmetry (Nielsen & Rendall, 2011; Ozturk et al., 2013). This allowed us to show that the contribution of each phoneme to this asymmetry is not the same. Specifically, we showed that even for vowels that have previously been found to be consistently associated to round and spiky shapes (e.g., /o,u/ vs. /i,e/), the influence varies as a function of the consonantal context: when combined with certain consonants, the effect was weak (/l/, /m/, /t/, /z/ in experiment 2) or even absent (i.e., /b/ in experiment 3). By contrast, the influence of consonants is more stable in that it depends less on the vocalic context.

All in all, our data clearly demonstrates that listeners are influenced more by consonants than by vowels to associate pseudowords with visual shapes. This is in line with the literature pertaining to the differential role that consonants and vowels may play in speech perception (Bonatti et al., 2005; Caramazza et al., 2000; Cutler et al., 2000; Mehler et al., 2006; New & Nazzi, 2014; Toro, Nespor, et al., 2008; Toro, Shukla, et al., 2008). Cutler et al. (2000) showed that both Dutch and Spanish participants would rather alter a vowel than a consonant to turn a pseudoword into a real word. For instance, they turned “kebra” into “cobra” rather than into “zebra”. In the same vein, Bonatti et al. (2005) found that adults can track statistical regularities among consonants but not among vowels when segmenting words from a continuous auditory stream of artificial speech. Findings like these demonstrate that consonants are more important than vowels in lexical access. Assuming that the bouba-kiki effect involves some processing at a lexical level, this hypothesis could explain why this sound–shape mapping process depends more upon consonants than upon vowels. Whether the fact that consonants are more informative than vowels for lexical access is a result of an innate language module (Bonatti et al., 2005) or the result of exposure to the lexical regularities of one’s native language (Keidel, Jenison, Kluender, & Seidenberg, 2007) remains an open question and should be explored in future research.

To conclude, among all the cross-modal or cross-sensory correspondences observed so far (see Marks, 2004 and Spence, 2011 for reviews), the bouba-kiki effect seems to be the most complex one. Indeed, since its discovery in 1947, no phonological or acoustic feature or set of features has been identified as being responsible for this effect. This is not surprising, as unlike most other cross-modal correspondences, the bouba-kiki effect involves auditory speech events rather than simple stimuli that vary across a single physical dimension, such as pitch or loudness. Thus, the bouba-kiki effect could be influenced by a host of factors, including acoustic, articulatory, and phonological properties of the speech stimuli[5] (see Spence, 2011 and Walker, 2012 for similar arguments). Further research is needed to systematically test the possible influences of these different factors on the bouba-kiki effect.

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Notes

1. C=Consonant, V=Vowel.
2. Out of the 36 possible items (9 vowels × 2 consonant pairs × 2 orders), 4 were excluded because they corresponded to French words.
3. These similar colors were chosen such as to minimize the possibility of color having an effect.
4. Out of the 60 possible items (15 consonants × 2 vowel pairs × 2 orders), 4 were excluded because they correspond to French words.
5. Note that other factors, such as orthography, also may play a role (see Westbury, 2005).

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Appendix A. Auditory stimuli used in experiment 1.

Consonant pair	Vowel identity	List 1	List 2
/l,m/	/a/	–	/mala/
	/ɑ̃/	/lɑ̃mɑ̃/	/mɑ̃lɑ̃/
	/e/	–	/leme/
	/ɛ̃/	/mɛ̃lɛ̃/	/lɛ̃mɛ̃/
	/i/	/limi/	/mili/
	/o/	/lomo/	–
	/ø/	/mølø/	/lømø/
	/u/	/lumu/	/mulu/
	/y/	/myly/	/lymy/
/t,k/	/a/	/taka/	/kata/
	/ɑ̃/	/tɑ̃kɑ̃/	/kɑ̃tɑ̃/
	/e/	/teke/	/kete/
	/ɛ̃/	/kɛ̃tɛ̃/	/tɛ̃kɛ̃/
	/i/	/tiki/	/kiti/
	/o/	/toko/	–
	/ø/	/køtø/	/tøkø/
	/u/	/kutu/	/tuku/
	/y/	/kyty/	/tyky/

Appendix B. Auditory stimuli in experiment 2.

Consonant pair	Vowel identity	Items
/l,m/	/a/	/ala/
		/ama/
	/ɑ̃/	/ɑ̃lɑ̃/
		/ɑ̃mɑ̃/
	/e/	/ele/
		/eme/
	/ɛ̃/	/ɛ̃lɛ̃/
		/ɛ̃mɛ̃/
	/i/	/ili/
		/imi/
	/o/	/olo/
		/omo/
	/ø/	/ølø/
		/ømø/
	/u/	/ulu/
		/umu/
	/y/	/yly/
		/ymy/
/t,k/	/a/	/ata/
		/aka/
	/ɑ̃/	/ɑ̃tɑ̃/
		/ɑ̃kɑ̃/
	/e/	/ete/
		/eke/
	/ɛ̃/	/ɛ̃tɛ̃/
		/ɛ̃kɛ̃/
	/i/	/iti/
		/iki/
	/o/	/oto/
		/oko/
	/ø/	/øtø/
		/økø/
	/u/	/utu/
		/uku/
	/y/	/yty/
		/yky/

Appendix C. Auditory stimuli in experiment 3.

Vowel pair	Consonant identity	List 1	List 2
/i,e/	/b/	/bibe/	/bebi/
	/d/	/dide/	/dedi/
	/g/	/gige/	/gegi/
	/p/	–	/pepi/
	/t/	/teti/	/tite/
	/k/	/keki/	/kike/
	/v/	/vevi/	–
	/z/	/zezi/	/zize/
	/ʒ/	/ʒeʒi/	/ʒiʒe/
	/f/	/fefi/	/fife/
	/s/	/sise/	/sesi/
	/ʃ/	/ʃiʃe/	/ʃeʃi/
	/m/	/memi/	–
	/n/	/nine/	/neni/
	/l/	–	/leli/
/o,u/	/b/	/bobu/	/bubo/
	/d/	/dodu/	/dudo/
	/g/	/gogu/	/gugo/
	/p/	/popu/	/pupo/
	/t/	/tuto/	/totu/
	/k/	/kuko/	/koku/
	/v/	/vuvo/	/vovu/
	/z/	/zozu/	/zuzo/
	/ʒ/	/ʒoʒu/	/ʒuʒo/
	/f/	/fufo/	/fofu/
	/s/	/suso/	/sosu/
	/ʃ/	/ʃuʃo/	/ʃoʃu/
	/m/	/momu/	/mumo/
	/n/	/nonu/	/nuno/
	/l/	/lulo/	/lolu/

Appendix D. Table of results for experiment 1.

Variable	Estimate (β)	SD	*z*	*p*
(Intercept)	−0.434	−0.304	−1.427	.154
Vowel identity: /e/	−0.808	0.456	−1.771	.077
Vowel identity: /ø/	−0.581	0.442	−1.315	.189
Vowel identity: /a/	−0.691	0.448	−1.542	.123
Vowel identity: /i/	−1.371	0.589	−2.694	.007
Vowel identity: /ɛ̃/	−0.090	0.422	−0.214	.831
Vowel identity: /o/	−0.086	0.418	0.212	.832
Vowel identity: /u/	−2.301 e−6	0.420	0	.999
Vowel identity: /y/	−0.476	0.436	−1.090	.276
Consonant pair	2.876	0.068	4.741	2.13 e−6
Consonant pair × vowel identity /e/	0.808	0.876	0.922	.357
Consonant pair × vowel identity /ø/	0.581	0.869	0.668	.504
Consonant pair × vowel identity /a/	0.235	0.822	0.286	.775
Consonant pair × vowel identity /i/	−0.162	−0.801	−0.202	.840
Consonant pair × vowel identity /ɛ̃/	−0.853	0.773	−1.103	.270
Consonant pair × vowel identity /o/	0.224	0.906	0.247	.805
Consonant pair × vowel identity /u/	−6.369	0.792	−0.804	.421
Consonant pair × vowel identity /y/	4.751	0.866	0.549	.583

Appendix E. Table of results for experiment 2.

Variable	Estimate (β)	SD	*z*	*p*
(Intercept)	−0.354	0.430	−0.823	.411
Vowel identity: /e/	−1.331	0.699	−1.904	.057
Vowel identity: /ø/	−0.580	0.619	−0.937	.349
Vowel identity: /a/, /i/, /ɛ̃/, /y/	−0.376	0.606	−0.620	.535
Vowel identity: /o/	−0.702	0.798	−0.880	.379
Vowel identity: /u/	−0.184	0.598	−0.308	.758
Consonant pair	2.843	0.868	3.277	.001
Consonant pair × vowel identity /e/	0.445	1.304	0.341	.733
Consonant pair × vowel identity /ø/	0.580	1.240	0.467	.640
Consonant pair × vowel identity /a/	0.300	1.452	0.204	.838
Consonant pair × vowel identity /i/	−0.430	1.122	−0.383	.701
Consonant pair × vowel identity /ɛ̃/	−0.085	1.160	−0.073	.942
Consonant pair × vowel identity /o/	15.930	1928.407	0.008	.993
Consonant pair × vowel identity /u/	15.342	1363.672	0.011	.991
Consonant pair × vowel identity /y/	−0.085	1.160	−0.073	0.942

Appendix F. Table of results for experiment 3.

Variable	Estimate (β)	SD	*z*	*p*
(Intercept)	−7.204 e−5	0.413	0	.999
Consonant identity: /b/, /ʃ/, /d/, /n/, /l/, /m/	2.432	0.851	2.857	.004
Consonant identity: /g/	1.976	0.745	2.652	.008
Consonant identity: /ʒ/, /s/, /p/	1.359	0.651	2.087	.037
Consonant identity: /k/	−0.171	0.580	−0.294	.769
Consonant identity: /t/	−3.217 e−5	0.579	0	.999
Consonant identity: /v/	0.707	0.597	1.183	.237
Consonant identity: /z/	−0.904	0.610	−1.483	.138
Vowel pair	−0.343	0.583	0.588	.556
Vowel pair × consonant identity /d/	−3.296	1.037	−3.177	.002
Vowel pair × consonant identity /p/	−3.437	1.101	−3.123	.002
Vowel pair × consonant identity /ʃ/	−3.118	1.034	−3.015	.003
Vowel pair × consonant identity /n/	−2.604	1.032	−2.523	.012
Vowel pair × consonant identity /g/	−2.319	0.9464	−2.451	.014
Vowel pair × consonant identity /ʒ/	−1.872	0.8747	−2.14	.032
Vowel pair × consonant identity /v/	−2.064	0.9913	−2.082	.037
Vowel pair × consonant identity /k/	−1.809	0.9024	−2.005	.045
Vowel pair × consonant identity /s/, /t/	−1.702	0.874	−1.947	.052
Vowel pair × consonant identity /z/	−1.871	1.050	−1.782	.0747
Vowel pair × consonant identity /m/	−1.040	1.228	−0.847	.397
Vowel pair × consonant identity /b/	−0.799	1.133	−0.705	.481
Vowel pair × consonant identity /l/	−0.449	1.419	−0.316	.752