The development of spontaneous sound-shape matching in monolingual and bilingual infants during the first year

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Abstract:

Recently it has been proposed that sensitivity to non-arbitrary relationships between speech sounds and objects potentially bootstraps lexical acquisition. However, it is currently unclear whether preverbal infants (e.g., before 6 months of age) with different linguistic profiles are sensitive to such non-arbitrary relationships. Here, we assessed 4- and 12-month-old Basque monolingual and Spanish-Basque bilingual infants' sensitivity to cross-modal correspondences between sound symbolic non-words without syllable repetition ('buba', 'kike') and drawings of rounded and angular shapes. Our findings demonstrate that sensitivity to sound-shape correspondences emerge by 12 months of age in both monolinguals and bilinguals. This finding suggests that spontaneous sound-shape matching is likely to be the product of language learning and development and may not be readily available prior to the onset of word learning.

Introduction

It is established that children and adults are sensitive to non-arbitrary cross-modal correspondences (for review, see Spence, 2011). A well-known example of this research is the tendency in adults and children to associate rounded shapes with specific types of speech sound combinations (e.g., "bouba"), but angular shapes with other types of speech sounds (e.g., "kiki"). This phenomenon is often referred to as the *bouba-kiki effect,* or *sound symbolism* and it has been extended to other non-word pairs, such as "maluma" and "takete", or "dom" and "shick", among many others (e.g., Kovic, Plunkett & Westermann, 2010). While sound symbolic associations are also observed with non-linguistic sounds (e.g., associations between auditory pitch and object size; Fernandez-Prieto, Navarra, & Pons, 2015), here we focus on cross-modal correspondences between speech and shapes (the bouba-kiki effect), because of its potentially relevant role in early language development.

It has been recently proposed that sensitivity to sound symbolic associations are present at the earliest stages of linguistic development and it bootstraps the initial stages of word learning by providing a *referential role* to spoken language (i.e., speech can refer to objects; Imai & Kita, 2014). The referential role of speech might be facilitated by sound symbolism through preverbal infants' spontaneous sensitivity to the non-arbitrary cross-modal relationships between certain speech sounds that can refer to objects or their features, as a referent. Yet, whether such sensitivities are in fact present prior to the onset of word learning (e.g., before 6 months of age; Bergelson & Swingley, 2012), or whether sound symbolic association preferences emerge as a result of language and/or cognitive development, is an unresolved question. While 3-4 months-

old infants are able to categorize objects if they are labeled with speech sounds, as opposed to with non-linguistic tones (Ferry, Hespos & Waxman, 2010), word-learning skills fully emerge by ~2-3-years of age. By this age, toddlers demonstrate adult-like sound symbolic matching preferences (e.g., Maurer, Pathman & Mondloch, 2006; Imai et al., 2008). By the time referential communication fully develops, towards the end of the first year of life, (e.g., Bates, Camaioni, & Volterra, 1975; also see, Marno et al., 2015); infants' neural activity reflects sensitivity to non-arbitrary relationships between linguistic labels and shapes. Asano et al., (2015) recorded neurophysiological responses from eleven-month-old Japanese infants and found evidence for a more effortful integration process when hearing a sound symbolic mismatch ("kipi"), as opposed to a sound symbolic match ("moma"), after the visual presentation of a round shape.

The findings in infants younger than 6 months of age are less straightforward. This period in development is relevant here because infants exhibit no clear evidence of word learning abilities before this age (Bergelson & Swingley, 2012); however, they are capable of perceiving whether certain combinations of auditory and visual linguistic information at the phonetic/syllable level match or not (e.g., Burnham & Dodd, 2004; Yeung & Werker, 2013). Therefore, evidence for the bouba-kiki effect before 6 months of age would support the sound symbolism bootstrapping hypothesis proposed by Imai & Kita (2014). Thus far, two studies have assessed sound symbolic matching preferences in infants younger than 6 months of age. French-learning infants between 5 and 6 months of age show no sensitivity to linguistic cross-modal correspondences using sound symbolic non-words, such as "lomo", as a match for rounded, and "tiki", as

a match for angular shapes (Fort et al., 2013; also see, Lewkowicz & Minar, 2014). However, when the sound symbolic non-words 'kiki' and 'bubu' (as a variation of 'bouba') are used, 4-month-old infants from an English-speaking environment exhibit the bouba-kiki effect (Ozturk, Krehm, & Vouloumanos, 2013). Specifically, when infants were presented with mismatch trials (when 'kiki' was paired with rounded, and 'bubu' was paired with angular shapes) in a preference looking paradigm, they displayed significantly longer looking times than during the match trials ('bubu' was presented with rounded shapes, and 'kiki' was presented with angular shapes), suggesting that the infants spontaneously associated sound symbolic non-words with shapes.

Two points are relevant in regard to the non-words used by Ozturk et al. (2013). First, when other variations of bouba-kiki were presented to the infants in the same paradigm, such as 'kuku' vs. 'kiki' or 'bubu' vs. 'kuku', no sound symbolism effect was observed at 4 months of age (Ozturk et al., 2013). According to the sound symbolism research, 'k' and 'i' are sounds that are associated with angular shapes, and 'b' and 'u' are associated with rounded shapes (for review see Nielsen and Rendall, 2011). Therefore, when sound symbolically mixed sounds ('kuku') were contrasted with clearly sound symbolic items ('kiki' or 'bubu'), no effect was observed for any of the stimulus items, not even for 'kiki'. Second, Ozturk et al. (2013), unlike Fort et al. (2013), used non-words with repeated syllables (or reduplications) that entail the repetition of phonetic material in the stimuli. In this way, one may argue that the phonetic information becomes more salient in this stimuli set as opposed to sound symbolic words without syllable repetition. In addition, it has been suggested that infants utilize different

cognitive mechanisms when processing words or speech units with repeated syllable structure than those without such reduplications (Endress, Nespor, & Mehler, 2009).

Because most previous research has demonstrated sound symbolic associations in adults, toddlers, and infants using stimuli without reduplication (e.g., Asano et al., 2015; Maurer et al., 2006; Imai et al., 2008), and because we intended to avoid any potential confound effects induced by syllable repetition (e.g., Endress et al., 2009), we opted for a variation of the bouba-kiki paradigm that contains no syllabic reduplication: "buba" vs. "kike". Then, we set up the same testing procedure and recruited the same sample size as Ozturk et al. (2013). We also verified that the auditory stimuli used by Ozturk et al (2013) and the ones used in the current study elicited the same cross-modal matching preferences in adults. Twenty-four adults were just as likely to match "buba" with rounded shapes and "kike" with angular shapes (100%, N=12), as they were to match "bubu" with rounded shapes and "kiki" with angular shapes (100%, N=12); the procedure is described in Supplemental Material.

Moreover, we assessed spontaneous sound-shape matching preferences in two types of language population. The first group consisted of 4-month olds with monolingual (Basque) exposure, following Ozturk et al. (2013) and Fort et al. (2013). We predicted that if monolingual infants are equally sensitive to sound symbolic non-reduplications and reduplications then Basque monolingual 4-month-olds should exhibit spontaneous sound symbolic matching for the speech sound combinations of "bouba" and "kike", similarly to Ozturk et al. (2013). As a second group, we recruited infants with Basque-Spanish bilingual language exposure, to test whether a different type of language experience (monolingual vs. bilingual) can modify sound symbolic sensitivity.

Bilingual exposure has been shown to modulate infants' attention to cross-modal information (e.g., Pons, Bosch, & Lewkowicz, 2015); therefore, it is possible that bilingual infants exhibit matching preferences earlier than monolinguals. However, it is also relevant to consider here that native Basque-speaking adults demonstrate a stronger bouba-kike effect than native Spanish-speaking adults (Pejovic, Molnar, Yee, Martin, 2015). Basque speakers may be more sensitive to this effect because the quantity of real sound symbolic words is higher in Basque than in Spanish (Ibarretxe-Antuñano, 2009)[1]. Therefore, if the type of language exposure (e.g., exposure to a more sound symbolic language or the lack thereof) shapes young infants' matching abilities, then it is also a possibility that bilingual infants show decreased (i.e., later in development) matching sensitivity, because overall they receive less exposure to Basque than the monolingual infants.

Experiment 1

Method

Participants

Data from 26 full-term 4-month-old infants recruited from the Basque country were included in the final analysis. An additional 9 infants were tested but excluded from the analysis due to fussiness or crying (6) or equipment failure (3). Infants' language background was evaluated using a language background questionnaire (details in

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[1] Languages contain real sound symbolic word classes (e.g., ideophones, expressives, phonaesthemes, etc.) that have an iconic relationship between sounds and meaning (e.g., English words starting with "sn" are often related to the nose: *sneeze, snore, sniff, snorkel,* etc.). Also, non-Indo-European languages such as Basque are richer in sound symbolic words than Indo-European languages such as English and Spanish (e.g., Imai & Kita, 2014).

Supplemental Material). Thirteen infants (mean age = 123.8 days; range: 118 days to 129 days; girls = 9) were assigned to the *monolingual Basque group* (average Basque exposure = 97.3 %) and 13 infants were exposed to both languages regularly and constituted the *bilingual group* (mean age = 124 days, range 118 to 132 days; girls = 6; average Basque exposure = 52.2 %). Sample size for each language group was determined based on the original study of Ozturk et al. (2013). The original study had the sample size of 12 infants, and in the current study each group's sample size was 13.

Materials and Procedure

Auditory stimuli were prepared similarly to Ozturk et al. (2013; for description see Supplemental Material). Instead of the non-word 'kiki', however, we opted for 'kike'. With this change we controlled for the syllable repetition present in 'kiki' (already absent in 'buba')[2]. The visual stimuli (drawings of rounded vs. angular shapes) were identical to those used by Ozturk et al. (2013). The auditory and visual stimuli were also combined as in Ozturk et al. (2013): 8 *congruent* trials and 8 *incongruent* trials were created. Congruent trials included 4 congruent rounded trials (rounded shape paired with 'buba'), and 4 congruent angular trials (angular shape paired with 'kike'). The incongruent trials consisted of either the rounded visual stimuli paired with 'kike' (4 trials) or the angular visual stimulus paired with 'buba' (4 trials). One pre- and one post-test trial (Figure 1, panel B) were presented before and after the test trials, respectively.

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[2] Because in Spanish 'kike' can be used as a short version for the name Enrique, infants who had this name themselves or had somebody in their immediate environment with this name were excluded from participation (n=1).

The trials were pseudo-randomized into four blocks, each block containing one of the 4 trial types described above (Figure 1, panel A). Six presentation orders of the blocks were prepared and evenly assigned across the infants. Identical to Ozturk et al. (2013), infants' looking preferences in response to the congruent vs, incongruent trials were measured using a behavioral cross-modal matching looking paradigm. Each trial was maximum 40 seconds and was presented until the infant looked away for at least 2 seconds. For description of the procedure see Supplemental Material. We predicted that if infants have spontaneous matching preferences, then they would look longer when the incongruent, as opposed to the congruent trials are presented, similarly to Ozturk et al. (2013).
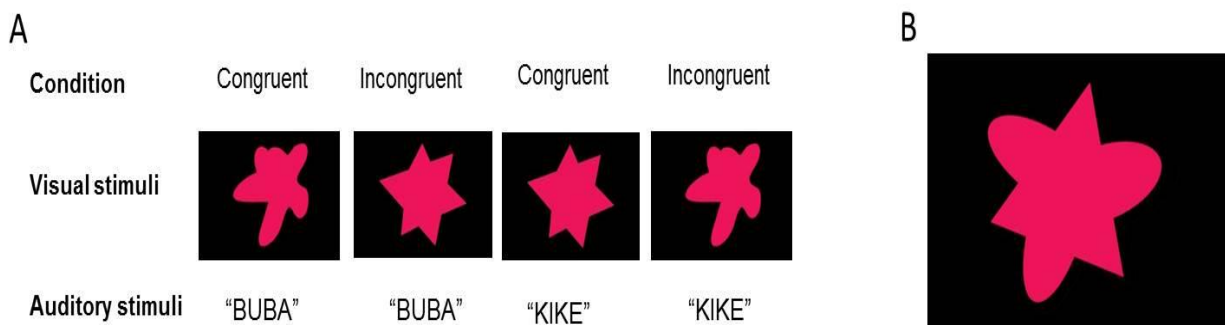

Figure 1. Panel A: An example of one trial block. Each block consisted of two congruent (buba matched with rounded shape and kike matched with a spiky shape) and two incongruent trials (buba paired with spiky shape and kike paired with a round shape). Infants were presented with four blocks in total. Six different lists with pseudorandomized order were assigned across infants. Panel B. Pre- and Post-test visual stimuli (a combination of a round and a spiky shape) was presented with baby-friendly music. The visual stimuli were from "Sound Symbolism in Infancy: Evidence for Sound-shape Cross-modal Correspondences in 4-month-olds," by O. Ozturk, M. Krehm, and A. Vouloumanos, 2013, *Journal of Experimental Child Psychology*, 114(2), p. 177. Copyright 2013 by Elsevier. Reprinted with permission.

Results and discussion: Experiment 1

Infants' looking times (in seconds) in response to the congruent and incongruent trials were averaged separately (Table 1). The average looking times by *Condition* (Congruent vs. Incongruent; within-subject factor) and by *Group* (Basque, Bilingual; between-subject factor) were submitted to a repeated ANOVA. The analyses yielded no significant effects of Condition ($F_{(1,24)} = .31$, $p = .6$; see Figure 2) or Group ($F_{(1,24)} = .00$, $p = .98$), and no interaction was observed between the two factors ($F_{(1,24)} = .3$, $p = .6$). Paired t-tests on the averages within the groups or combined across the groups did not reach significance (Basque group $t_{(12)} = -.9$, $p = .4$; Bilingual group $t_{(12)} = -.01$, $p = .9$; or combined across the groups $t_{(25)} = -.6$, $p = .6$). Moreover, repeated factorial ANOVAs by group found no significant effect of visual stimuli (rounded shape vs. angular shape) or the type of auditory stimuli (rounded word vs. angular word), suggesting that the type of visual or auditory stimuli did not modulate infants' behavior (within Basque group all $F < 1$, all $p > .4$; within Bilingual group all $F < 1$, all $p > .6$). Since we did not find the congruency effect with twice the sample size as the original Ozturk et al. (2013) study, we stopped data collection.

While infants of the same age, from English-speaking environment, looked significantly longer when incongruent trials were presented (as opposed to congruent ones; Ozturk et al. (2013), Basque monolingual and Spanish-Basque bilingual infants' looking behavior in the current study did not vary as a function of trial type (congruent vs. incongruent). Therefore, no evidence for sound-shape correspondence preferences was observed in the current study at 4 months of age. Moreover, no effect of linguistic

background was present, and therefore neither Basque nor bilingual exposure affects sound-shape matching biases in 4-month-olds.

Unlike in adults and toddlers, the current and previous studies suggest no spontaneous sound-shape association preferences present in infants before 6 months of age in response to non-words without syllable repetition (Fort et al., 2013; but see, Ozturk et al., 2013). These findings can be explained by at least two coinciding factors. First, infants might need to accumulate more linguistic experience to consistently exhibit sound-shape matching biases similarly to toddlers and adults. For instance, before exhibiting spontaneous sound-shape matching, infants need to learn that speech can have a referential role in the environment. Second, the infant brain undergoes important structural and functional changes during the first year of life and certain neural (and hence cognitive) maturation might be necessary to efficiently process events that require cross-modal integration (e.g., Gilmore et al., 2012; also see, Fernandez-Prieto et al., 2015). For this reason in Experiment 2 we tested older 12-month-old infants' matching sensitivity, using the same paradigm as in Experiment 1. By this age, infants demonstrate knowledge about the referential role of spoken language (e.g., Bates et al., 1975).

We predict that if language/cognitive development is necessary for the bouba-kiki effect to surface in infants, and it is not our specific stimuli pair ("buba" vs. "kike") that hinders the effect, then 12-month-olds will exhibit matching preferences. Also, it is a possibility that by this age the type of language input the infants receive (monolingual vs. bilingual or exposure to languages rich in sound symbolism) will interact with the

matching preferences, hence monolingual and bilingual infants can exhibit different patterns.

Experiment 2

Method

Participants

Twenty-six full-term 12-month-old infants were included in the analyses. An additional 6 infants were tested but excluded from analysis due to fussiness or crying (5), or parents' interference (1). Thirteen infants (mean age= 353 days; range: 331 days to 372 days; girls = 5; average Basque exposure = 98.3%) were assigned to the *monolingual Basque Group;* and 13 infants (mean age = 364.7 days; range 348 to 381 days; girls = 11; average Basque exposure = 65.7%) were assigned to the *bilingual group*. The materials and the procedure in Experiment 2 were identical to those in Experiment 1.

Results and discussion: Experiment 2

Infants' average looking times (Table 1) in response to the congruent and incongruent trials were submitted to an ANOVA, with *Condition* as within-subject factor (Congruent and Incongruent) and *Group* as a between-subject factor (Basque monolingual and Bilingual). The analyses yielded a significant effect of *Condition* ($F_{(1,24)}$ = 4.5; *p*=.045), where incongruent trials (M = 11.6, SD = 4.9) elicited longer looking times than congruent trials (M = 10.4, SD =4.3; see Figure 2). Neither the main effect of *Group*

($F_{(1,24)}= .07$, $p =.8$) nor the interaction term ($F_{(1,24)} = .3$, $p=.6$) reached significance. Similarly to Experiment 1, repeated factorial ANOVAs by group showed no effect of the type of visual or auditory stimuli on the infants' behavior (within Basque group, all $p >.1$; within Bilingual group).

Therefore, monolingual Basque and Basque-Spanish bilingual 12-month-olds looked longer during the presentation of incongruent than congruent trials, similarly to the 4-month-old English-learning infants (Ozturk et al., 2013), and exhibited sensitivities to sound-shape correspondences similarly to Japanese 11-month-olds (Asano et al., 2015). However, 12-month-old infants' looking behavior in our study did not vary as a function of the type of linguistic experience, and both Basque-learning and bilingual infants exhibited similar behavioral patterns.

	Group	Congruent Trials (seconds)	Incongruent Trials (seconds)	Percentage of infants preference to Incongruent trials (binominal test p-value)
Experiment 1 (4 months)	Basque Monolingual	14.5 (1.8)	15.7 (1.9)	50% (p=.58)
	Basque-Spanish Bilingual	15.2 (1.7)	15.2 (2.0)	
Experiment 2 (12 months)	Basque Monolingual	10.3 (0.9)	11.2 (0.9)	69% (p=.04)
	Basque-Spanish Bilingual	10.5 (1.5)	12.0 (1.7)	

Table 1. Mean looking times (in seconds) and standard error for each group and condition. The percentage of infants looking longer during the incongruent trials within each experiment is also reported. The *p*-values show the significance level of a binomial test comparing the number of infants who showed congruent vs. incongruent preference during the task.

Experiment 1 vs. Experiment 2

While the two age groups across the two experiments revealed different preference patterns, to assess whether the looking patterns of the two age groups significantly differs, we compared their performance in a mixed repeated ANOVA (*Age*: 4 and 12 months, as a between factor; *Condition*: congruent and incongruent, as a within factor). The analysis revealed a significant main effect of Age ($F_{(1, 50)} = 8.02$, $p = 0.007$; all other effects $p > 0.1$), reflecting that the overall looking times of the 4-month-olds were longer than those of the 12-month-olds (also see Figure 2), in line with developmental changes in infants' looking behavior (e.g., younger infants tend to look longer than older infants; Hunter, Ames & Koopman, 1983). To better understand the role of this specific developmental pattern, we built two linear mixed-effect models using SPSS 19.0. In the first one, we included *Age*, *Condition* and *Language group* as fixed effects. Subjects and intercept were included as random effects. Similarly to the mixed ANOVA, a main effect of *Age* reached significance ($F_{(1, 49)} = 7.9$, $p = 0.007$; all other effects $p > 0.1$). In the second model, however, we excluded *Age* as a main factor, hence we removed the factor from our analyses that is mainly due to developmental changes in attention (e.g., younger infants tend to look longer than older infants). This model yielded a significant interaction of *Age* and *Condition* ($F_{(2, 90.6)} = 4.03$, $p = 0.02$), and importantly no other main effects or interactions reached significance. (More details on the analysis can be found in the Supplemental Material). Overall, the comparison revealed that *Age* is a factor that strongly distinguishes the two groups, but once it is accounted for, the matching preference is only present in the older age group (see Figure 2).
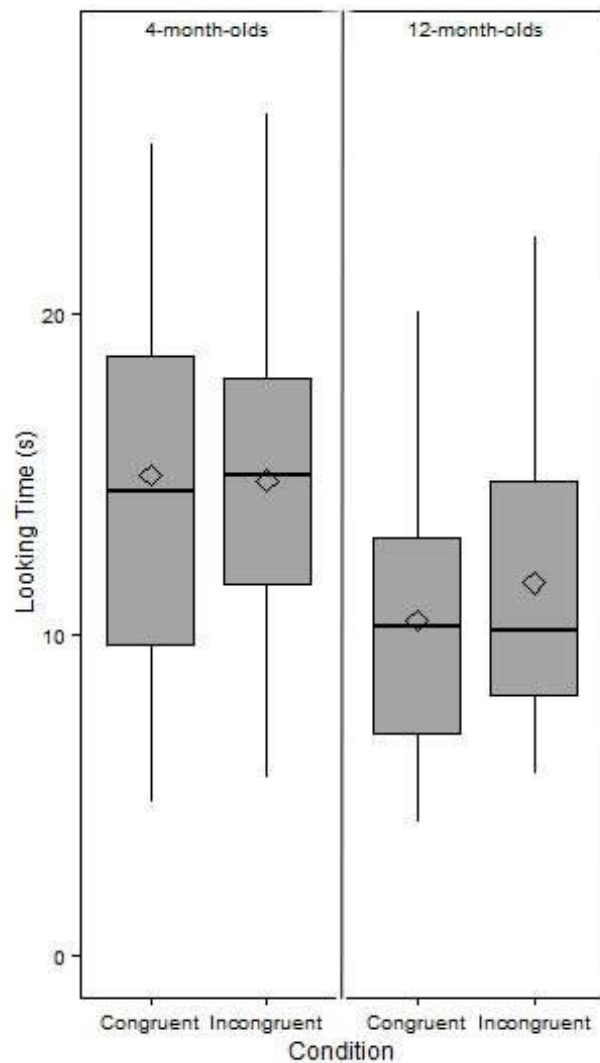
Figure 2. Boxplot of the *Looking times* of two age groups (4- and 12-month-olds) across the two conditions (*Congruent* vs. *Incongruent*). The horizontal line in the boxplot represents the median. The upper and lower portions of the box above and below the median represent the first and third quartiles, respectively. The whiskers represent 1.5 times inter-quartile range. The rhombuses represent the mean value of *Looking time* for each group and condition.

Discussion

Our results suggest that sensitivity to sound-shape correspondences changes

during the first year of life. While the bouba-kiki effect is detected in infants around 11-

12 months of age (Experiment 2 of this study; Asano et al., 2015), in toddlers, and adults (e.g., Maurer et al., 2006; Imai et al., 2008; Imai & Kita, 2014; Spence, 2011; etc.), young infants only show sensitivities to arbitrary speech-sound correspondences before 6 months of age under specific circumstances (Experiment 1 of this study; Fort et al., 2013; Ozturk et al., 2013 when using non-words with syllable repetitions). Considering the sound symbolism bootstrapping hypothesis (Imai & Kita, 2014), our results suggest that linguistic sound-shape matching preferences reliably emerge by a developmental period when word learning has already started (e.g., Bergelson & Swingley, 2012; Werker & Yeung, 2005), and sufficient neural/cognitive resources are available for detecting cross-modal correspondences (e.g., after 6 months of age; also see, Fernanadez-Prieto et al., 2015; Lewkowicz & Minar, 2014). Therefore, the ways in which sound symbolism and word learning development interact remain unclear.

It is also a possibility that infants younger than 6 months show spontaneous speech-sound matching in response to specific type of speech stimuli only, such as reduplications, as demonstrated by Ozturk et al., 2013. Indeed, reduplication is an important part of infant-directed speech and it presumably plays a role in early vocabulary development (e.g., Endress et al., 2009). Therefore, further systematic investigations of what sort of sound symbolic word structures elicit spontaneous mapping between speech and shapes before 6 months of age could provide a more specific description of the interaction between sound symbolism and language development.

Considering all the currently available empirical findings, it is also likely that sound symbolism appears as a product of linguistic experience and development.

Infants exhibit the ability to match linguistic information from different modalities at an early age. For instance, 4.5-month old infants are capable of matching auditory speech information with visual information in talking faces, as they are able to match an auditory exemplar of the vowel 'u' with the visual rounded articulatory movements associated with the same vowel; moreover, they are also sensitive to the sensorimotor information associated with the production (Yeung & Werker, 2013). Therefore, one possible explanation is that speech sound-shape correspondences develop as a function of linguistic experience with the auditory, visual and sensorimotor properties of speech. Considering a specific example, 'buba' contains sounds that are produced with rounded articulatory gestures. For this reason, older infants, toddlers, and adults might prefer to match the sounds in 'buba' with rounded visual forms (as an extension of their linguistic experience). Given this idea, the referential role of sound symbolism could emerge in parallel with language development; although this notion is currently speculative, as infant data on sound symbolism and cross-modal matching preferences is sparse. Important to the current study though is that the observed matching patterns did not depend on the type of linguistic exposure the infants received. First, monolingual 4-month-olds, who received exposure to a language rich in sound symbolic words (Basque), exhibited no advantage in matching abilities. Also, 4-month-olds immersed in a bilingual environment showed no advantage or disadvantage compared to monolinguals. Then, at 12 months of age, monolingual and bilingual infants showed equal sensitivity to the bouba-kiki effect. This pattern suggests that certain level of linguistic/cognitive development is necessary for the cross-modal correspondence to manifest (similarly to Prieto et al., 2015); however, the type of linguistic experience (e.g.,

monolingual or bilingual, or exposure to languages naturally rich in sound symbolism)

plays no relevant role during the early development of sound symbolic associations.

Also, further research is needed to examine whether different linguistic experience

affects sound symbolism in the age range that has not been tested here (i.e., between 4

and 12 months; also see, Prieto et al., 2015).

Overall, our findings demonstrate that sensitivity to sound-shape

correspondences can be detected by the end of the first year in both monolingual and

bilingual infants. Because in the current study younger infants showed no matching

preferences, the causal relationship between infants' word learning skills and sound

symbolism remains unspecified. Infant word learning is a complex process described by

several accounts (e.g., Akhtar & Tomasello, 2000; Aslin & Newport, 2014; Saffran,

2014). It incorporates perceptual and conceptual knowledge based on associations and

access to referential information (Waxman & Gelman, 2011; Marno et al., 2015); further,

lexical acquisition strongly interacts with the development of speech perception and

production (Vihman, DePaolis, & Keren-Portnoy, 2014; Werker & Yeung, 2005).

Whether sound symbolism readily interacts with any of these aspects of word learning,

or whether sound symbolism emerges only as a product of language learning itself, is

still unclear.

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