ARTICLE IN PRESS

Cognition xxx (2010) xxx–xxx

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Structural generalizations over consonants and vowels in 11-month-old infants

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ARTICLE INFO

Article history:
Received 13 November 2009
Revised 21 May 2010
Accepted 21 May 2010
Available online xxxx

Keywords:
Rule learning
Consonants and vowels
Language acquisition
Speech perception
Functional asymmetries

ABSTRACT

Recent research has suggested consonants and vowels serve different roles during language processing. While statistical computations are preferentially made over consonants but not over vowels, simple structural generalizations are easily made over vowels but not over consonants. Nevertheless, the origins of this asymmetry are unknown. Here we tested if a lifelong experience with language is necessary for vowels to become the preferred target for structural generalizations. We presented 11-month-old infants with a series of CVCVCV nonsense words in which all vowels were arranged according to an AAB rule (first and second vowels were the same, while the third vowel was different). During the test, we presented infants with new words whose vowels either followed or not, the aforementioned rule. We found that infants readily generalized this rule when implemented over the vowels. However, when the same rule was implemented over the consonants, infants could not generalize it to new instances. These results parallel those found with adult participants and demonstrate that several years of experience learning a language are not necessary for functional asymmetries between consonants and vowels to appear.

1. Introduction

There are at least two major problems in language learning. First, learning the words composing the language, and second, acquiring a set of rules according to which they are organized. Recent research suggests that a "division of labor" between consonants and vowels may help to focus on the appropriate sources of information to solve these problems. In fact, experiments with adults have shown that consonants, more than vowels, constrain lexical access. For example, if a participant is presented with a nonsense word, and asked to change one of its letters to form a word, he will more likely change one of its vowels, preserving the consonantal information to drive the selection of the new word (Cutler, Sebastián-Gallés, Soler-Vilageliu, & van Ooijen, 2000). More recently, New, Araujo, and Nazzi (2008) used a visual masked-priming lexical decision task to explore the different weight of consonants and vowels during lexical access. They found that primes that preserved the consonants of the target word lead to faster reaction times than primes that preserved the vowels of the target word. The authors concluded that consonants were the primary source of lexical information. In a similar vein, it has been suggested that consonants are the preferred target for lexically-related statistical computations (Bonatti, Peña, Nespor, & Mehler, 2005). More specifically, results have shown that participants correctly segment from a continuous speech stream, and later recognize, nonsense words when they are defined over statistically-coherent consonantal frames, but not when they are defined over vocalic frames. Complimentarily, Toro, Nespor, Mehler, and Bonatti (2008) observed that participants familiarized with a series of nonsense words in which the vowels were arranged following a simple rule (for example, in a word containing three vowels, that the first

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doi:10.1016/j.cognition.2010.05.013

two vowels were the same, while the third vowel was different) easily generalized it to new items not heard before. When the consonants were arranged following the same simple rule, participants could not generalize it to new items (that is, they did not show any evidence of rule-learning, or structure generalization, over consonants). Importantly, consonants and vowels differ in several acoustic features, including that vowels tend to carry more energy than consonants (Ladefoged, 2001). Nevertheless, these processing differences do not seem to depend on the acoustical features of the consonants or the vowels used in the experiments, as the same pattern of results is found when more salient sonorant consonants are used (Toro, Shukla, Nespor, & Endress, 2008). In a related finding in the music domain Kolinsky, Lidji, Peretz, Besson, and Morais (2009) found that vowels are more closely linked than consonants to melody and pitch changes, and that these differences were largely independent of sonority. In speech, vowels are the main carriers of prosody through intonation and stress (Nespor & Vogel, 1986). As such, they signal linguistic rhythm, and are involved in marking certain syntactic parameters (as the relative order of head and complements in a given language) at the prosodic level (Nespor, Peña, & Mehler, 2003). Finally, vowels have been found to play a more important role in non-lexical aspects of linguistic processing such as talker identification through indexical cues (Owren & Cardillo, 2006). Thus, taken together, all the above-mentioned results support the hypothesis put forward by Nespor and collaborators (2003) that consonants are more heavily involved in lexical processing, while vowels are involved in different markings at the indexical and prosodic level.

Studies with young infants have suggested that sensitivity to distributional (Saffran, Aslin, & Newport, 1996) and structural cues (Marcus, Vijayan, Bandi Rao, & Vishton, 1999) aid in the acquisition of core linguistic regularities that include both lexical and grammatical information. More recently, some sensitivity to functional differences between consonants and vowels has been observed in infants during word learning tasks. Havy and Nazzi (2009) observed that 16-month-olds readily use consonants but not vowels, for learning new words. Specifically, the infants successfully learned two novel word pairs that differed only by a single consonant (e.g. /tize/-/kize/), but not when word pairs differed only by a single vowel (e.g. /dugi/-/dogi/). This pattern has also been found with 20-month-olds (Nazzi, 2005) and with both English- and French-learning infants (Nazzi, Floccia, Moquet, & Butler, 2009). Importantly, these results do not suggest that infants cannot adequately process vowels to signal lexical membership when the task guides them to do so (Mani & Plunkett, 2007, 2008), or when acoustic dimensions, such as vowel height, facilitate the word-object pairing (Curtin, Fennell, & Escudero, 2009). Rather, they reveal that the different role consonants and vowels are given during language processing tend to favor a stronger reliance on the consonants for word learning from an early age.

Nevertheless, if infants benefit from consonants and vowels signaling different aspects of the linguistic structure as adults do, their sensitivity to distributional and structural regularities should also be constrained by such information (see Bonatti et al., 2005; Toro et al., 2008). That is, apart from relying more strongly on consonants for lexical identification, infants should also perform differently on a structure generalization task when implemented over consonants in comparison to vowels. Additionally, if functional differences between consonants and vowels are relevant for language acquisition, infants should be sensitive to this distinction even before a complete lexicon is developed. In the current study we test this hypothesis, and assess if infants easily make structural generalizations over vowels but not over consonants. We thus run two experiments with 11-month-old infants. Previous experiments on the extraction of both statistical and structural regularities have been done with younger infants (7-month-olds, Marcus et al., 1999; 8-month-olds, Saffran et al., 1996). Instead, we decided to test 11-month-olds because it was important that the infants were able to readily process both vowels and consonants used in the present experiment. Research has shown that infants reorganize their phonetic perception around 10–11 months for consonants, and earlier, around 6 months, for vowels (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Werker & Tees, 1984). Even more, between 6 and 10 months of age, infants improve their discrimination of native contrasts (Kuhl et al., 2006; Narayan, Werker, & Beddor, 2010). Thus, by 11 months of age phonetic reorganization has already taken place and both consonants and vowels of the native language are readily processed by infants.

In the first experiment we presented infants with a series of trisyllabic CVCVCV nonsense words in which vowels followed a simple AAB structure (that is, the first and second vowel were the same, while the third vowel was different). After this familiarization phase, we presented infants with completely new words (with phoneme combinations not presented during the familiarization) in which the vowels either followed or not the AAB structure. The second experiment was identical in all respects to the first one, but the simple AAB structure was implemented over the consonants, instead of vowels.

2. Experiment 1

2.1. Participants

Sixteen healthy full-term 11-month-old infants (eight females) participated in Experiment 1. All infants were raised in monolingual Spanish families. According to parental report, daily exposure to this language ranged from 80% to 100%. The infants' mean age was 11:09 months (range: 11:04 to 11:23 months). Seven additional infants were tested, but not included in the final sample because of crying or fussiness (6), and experimental error (1). Participants were recruited through visiting new mothers at the Hospital Sant Joan de Déu. Parental consent was acquired before running the experiment.

2.2. Stimuli

We created a series of trisyllabic CVCVCV nonsense words combining five consonants (b, d, t, l, n) and five

Table 1
Lists of nonsense words used during familiarization and test for Experiment 1, with the structure implemented over the vowels.

Familiarization	Test *same*	Test *different*
dabale	nadato	dutone
tolode	batalo	lanude
tibilo	talabo	bitado
tabale	linide	tadino
lobote	tidine	nolida
dinilo	dilite	tulabe
badane	noloda	butida
notole	bodota	nedota
litino	lotoba	tanudo
tedeba	dutube	datino
ditiba	lubude	lubote
nuduto	bunute	budilo
benela		
bitida		
butudo		
leteda		
nidiba		
lunudo		

vowels (a, e, i, o, u). Importantly, vowels always followed an AAB structure (the first two vowels were the same, while the third vowel was different); while consonants were combined randomly, although repetitions within a word were avoided (e.g. *dabale*, *butudo*, *litino*; see Table 1). Eighteen words, implementing six different vowel combinations (*aae*, *ooe*, *iio*, *eea*, *iia*, *uuo*) were used for the familiarization phase. For the test phase, two lists composed of 12 new words were used. One list (*same structure*) contained words not previously presented, created identically to the ones used during familiarization (structured vowels and random consonants). These words were composed using the same phonemes used for the familiarization items, but arranged in combinations not used during familiarization, so they were novel to the infants. These words implemented four different vowel combinations (*aao*, *iie*, *ooa*, *uue*) not presented during familiarization. To use completely new phonemes would be problematic given the reduced vocalic inventory of the infants mother language (Spanish has only five vowels), and the risk of observing an increase of looking times at the test phase for both types of lists due to the use of new elements. The other list (*different structure*) contained words also composed with the same phonemes as those used during familiarization, but with vowels and consonants following an ABC structure (no repetition was allowed in either consonants or vowels, resulting in words such as *dabenu*, *tilobe*, *netuda*). Words were synthesized using MBROLA (Dutoit, Pagel, Pierret, Bataille, & van der Vrecken, 1996) with a female diphone database (it4). Phoneme duration was set to 150 ms, and pitch at 240 Hz. Total duration of each nonsense word was 900 ms. Words were presented with an inter-stimulus interval of 500 ms in both the familiarization and test phases.

2.3. Apparatus

Infants were tested in a three-sided test booth (1.6 m each side) within a sound-attenuated laboratory room. The experimenter controlled the experiment and continuously recorded infants' looking behavior through a Panasonic AG-7700 S-VHS system and a Panasonic BT-S1460Y TV monitor located on a control room. In the test booth, the infant was seated on the parent's lap facing three monitors on which an animated image was presented. Throughout the experiment, the parent listened to music through closed headphones. The chair was at a distance of 90 cm from the central monitor, and the lateral monitors were placed at 35° to the right and left sides. Two Sony SS-125 E loudspeakers were hidden below these two lateral monitors and were connected to a Sony TA-F2245R amplifier located in the control room. The loudness levels for the stimulus presentation were set at 65 ± 5 dB (A) SPL using an Onsoku SM-6 sound level meter. An assistant was present in the room to control and adjust the camera (DXC-107 TV camera plus a Sony CMA-D2 control unit) if necessary. The experimenter wore headphones that played music throughout the experiment, so that he was unaware of the materials presented to the infant. He faced the TV monitor to control infants' looking behavior. The experimenter decided when to start a trial and recorded online the attentional responses of the baby for every trial by depressing and releasing a key from the computer keyboard. The computer controlled the presentation of the images and the auditory material; it also recorded the coding of the duration of infants' visual fixation. This information was stored in a file and was later used to obtain infant's looking times.

2.4. Procedure

We used a modified version of the familiarization-preference procedure (Bosch & Sebastian-Galles, 2001; Skoruppa et al., 2009). The entire procedure took place in one session and comprised a familiarization phase immediately followed by a test phase. In the familiarization phase, the 18 words were randomly divided into two presentation lists of nine words each. Infants were presented with the words from the two lists until they had accumulated two minutes of sustained attention to this material. Each trial started with the presentation of an image on the central monitor. As soon as the infant looked in the direction of the monitor, it was turned off and one of the lateral monitors showed another image. When the infant's gaze was directed to the lateral monitor (a head turn of at least 30°), the auditory material from one of the lists was played. The image and audio remained on until completion of the trial, which occurred after three repetitions of the stimuli on the list (28 s), or until the infant ceased to look in that direction for more than two consecutive seconds. All fixation periods to one of the lateral monitors were registered to account for the total looking time. Lists of nonsense words were presented randomly on the left or on the right, with no more than two repetitions to the same side. The nonsense words that composed the lists were presented randomly every time a trial started. High variability in the material employed (18 different nonsense words) was intended to guarantee that if a differential response was found, it could be reliably attributed to a structural generalization and not merely to a word, or item recognition. Duration of the familiarization phase allowed

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all infants to be presented with at least two repetitions of each nonsense word. Once the infants accumulated two minutes of total attention to this material the test phase began. The test phase consisted of two trials in which infants always heard novel material. One trial contained a list of twelve new nonsense words sharing the AAB structure with the familiarization trials (*same structure*/AAB). The other list contained twelve new nonsense words with a different structure (*different structure*/ABC). The order of presentation of the test trials was counter-balanced. Each test trial lasted for 28 s, or until de infant ceased to look in the appropriate direction for more than two consecutive seconds. If infants extracted the underlying structure of words during familiarization, they should look longer to the list composed of stimuli with different structure than to the list composed of stimuli with the same structure.

2.5. Results

Mean looking times during the test phase were submitted to a repeated-measures ANOVA with 'trial structure' (same/AAB vs. different/ABC) as the within-subjects factor, and 'order' (same first vs. different first) as the between-subjects factor. Only an effect of 'trial structure' was observed, $F(1,14) = 5.857$; $p = .030$, $\eta_p^2 = .295$ ($M_{\text{different}} = 12.38$ s; $M_{\text{same}} = 9.43$ s), but no effect of order presentation nor interaction between these factors (see Fig. 1). Eleven out of 16 participants showed longer listening times to the different words (Wilcoxon signed ranks, $z(16) = -2.01$, $p = .044$). Thus, infants looked longer during the trial containing words with vowels following a different structure than during the trial with words with the same structure as in the familiarization phase. This suggests that infants detected the difference in the structure when it was implemented over the vowels. Next, we wanted to test if infants would also detect such difference when the structure was implemented over the consonants.

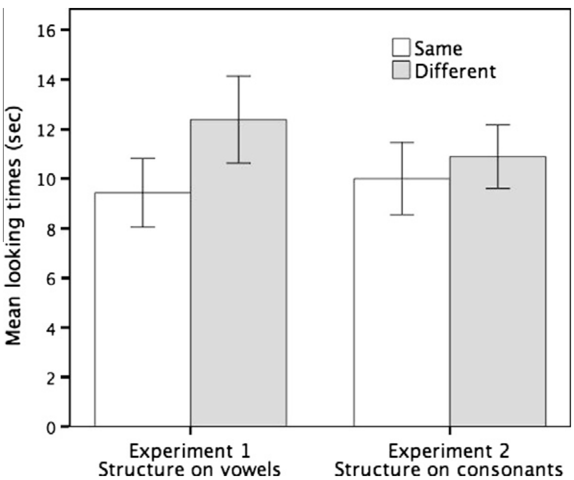

Fig. 1. Mean looking times and standard error bars for *same* and *different* test trials when the AAB structure was implemented over the vowels (Experiment 1) and over the consonants (Experiment 2).

3. Experiment 2

3.1. Participants

Sixteen healthy full-term 11-month-old infants (eight females) participated in this experiment. All infants were raised in monolingual Spanish families. According to parental report, daily exposure to this language ranged from 80% to 100%. The infants' mean age was 11:13 months (range: 11:08–11:21 months). Six additional infants were tested, but not included in the final sample because of crying or fussiness (5), and parental interference (1). Participants were recruited through visiting new mothers at the Hospital Sant Joan de Déu. Parental consent was acquired before running the experiment.

3.2. Stimuli and procedure

We created a series of trisyllabic CVCVCV nonsense words by combining the same five consonants (b, d, t, l, n) and five vowels (a, e, i, o, u) as in Experiment 1. In contrast to the previous experiment, consonants were always arranged following an AAB structure, while vowels were arranged randomly (only avoiding repetitions within each word), thus producing words such as *dadeno*, *bebila*, *nanide* for the familiarization phase (see Table 2). Words implemented six different consonant combinations (*ddn*, *llb*, *nnd*, *ttn*, *bbl*, *bbn*). In a similar manner, test items used for the test phase were arranged according to two lists. Words in the *same structure* list contained consonants following an AAB structure, and vowels arranged randomly. As in Experiment 1, these words implemented four different consonant combinations (*ddl*, *lln*, *nnb*, *ttd*) not presented during familiarization. Words in the *different structure* list were composed of the same phonemes, arranged in a random manner, so no evident structure was implemented over them. To be sure that familiarization and test items had a similar overlap across Experiment 1 and 2, we calculated the phoneme overlap (that is, number of phonemes present in the same position) between familiarization and test items for both the "same" and "different" lists, and computed a ratio between these. The overlap ratio for Experiment 1 was .2962 and for Experiment 2 it was .2978. Thus there were no major differences between phoneme overlap in the stimuli used in both experiments that could account for possible observed differences. Stimuli were synthesized as those in Experiment 1. The apparatus and procedure were also identical to that from Experiment 1.

3.3. Results

We submitted the mean looking times during the test phase to a repeated-measures ANOVA with 'trial structure' (same/AAB vs. different/ABC) as the within-subjects factor and 'order' (same first vs. different first) as the between-subjects factor. No effect of trial structure, $F(1,14) = 1.204$; $p > .1$, $\eta_p^2 = .079$ ($M_{\text{different}} = 10.88$ s; $M_{\text{same}} = 10.00$ s), order or interaction between these two factors was observed. Only 7 out of 16 participants showed

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Table 2
Lists of nonsense words used during familiarization and test for Experiment 2, with the structure implemented over the consonants.

Familiarization	Test *same*	Test *different*
dadeno	dedulo	dutani
lulabo	didola	litedo
nunide	dadeli	boneda
dudina	lilune	tidolu
ninado	lulina	bilune
tetino	loleni	nitado
dodane	nanibo	tabude
nanide	ninube	detulo
tatuno	nunobi	dabilu
bibule	titedo	tuneba
bubona	totude	nelobi
tatino	tetoda	labuno
bobine		
bebila		
lalube		
bibena		
lulibo		
babulo		

longer looking times to the different words (Wilcoxon signed ranks, $z(16) = -1.24$, $p = 0.215$). An analysis of variance comparing both experiments 1 and 2 revealed an effect of trial structure $F(1,30) = 6.433$; $p = .017$, $\eta_p^2 = .177$, but no effect of experiment ($F < 1$) nor interaction between them $F(1,30) = 1.860$; $p = .183$, $\eta_p^2 = .058$. This lack of interaction between the two experiments and trial structure was not unexpected. In our study, infants in Experiment 1 looked longer at trials containing words with a different vowel structure than to trials containing words with the same vowel structure. However, there is no reason for infants in Experiment 2 to show the opposite pattern, that is, to look longer at trials with the same consonantal structure than to trials with a different consonantal structure. Results indeed demonstrate that their looking times were similar for both types of trials, suggesting they did not extract the underlying structure when it was implemented over consonants. In fact, the effect size on Experiment 1 is more than three times as large as that from Experiment 2 ($\eta_p^2 = .295$ for Experiment 1, $\eta_p^2 = .079$ for Experiment 2). Thus, the non-significant interaction would support a constantly repeated claim: differences between consonants and vowels are not absolute, but rather relative (see Nespor et al., 2003; Toro et al., 2008). That is, our results do not rule out the possibility of finding generalizations over consonants (see below), but show that such generalizations are easily made over vowels but not over consonants.

4. General discussion

A central problem in understanding how language is learned is that it is unknown as to how infants extract relevant regularities from the linguistic input. It has been proposed that functional differences between consonants and vowels constrain computational mechanisms towards relevant sources of information (see Bonatti et al., 2005). In two experiments, we explored 11-month-olds' ability to make structural generalizations over consonants and vowels. We observed that infants readily generalize a simple AAB structure to new exemplars when such structure is instantiated over vowels (Experiment 1), but not when it is instantiated over consonants (Experiment 2). These results parallel those found with adults (Toro et al., 2008), and demonstrate that infants generalize simple structures more easily over vowels than over consonants, even before a complete vocabulary is in place.

It has been claimed that processing asymmetries between consonants and vowels may arise as a result of prolonged linguistic experience (e.g. Keidel, Jenison, Kluender, & Seidenberg, 2007). Even more, Spanish has a limited number of vowels (only five) and one might wonder if the present results may also be found in infants with a more balanced repertoire of consonants and vowels. However, our results, together with those showing that infants rely more strongly on consonants for word learning (Havy & Nazzi, 2009), demonstrate that such asymmetries seem to be present from an early age, and that several years of experience with a given language are not necessary for them to become apparent (see also Bonatti, Peña, Nespor, & Mehler, 2007). The fact that differences between consonants and vowels appear in both infants and adults, across different languages (Dutch, Cutler et al., 2000; English, Nazzi et al., 2009; French, Bonatti et al., 2005; Italian, Toro et al., 2008; Spanish, present study) and in both the acoustic and the visual modality (New et al., 2008) suggests such differences are an integral part of how the linguistic system is organized. Of course, by 11 months of age infants have already a significant linguistic experience, so our results do not suggest an innate bias to process differentially consonants and vowels. It is in fact very likely that experience plays an important role in such functional differentiation. Our results do suggest an early division of labor between different phonetic components that can be observed before a mature lexicon is in place. It would be nevertheless interesting to explore if infants immersed in a linguistic environment with a very similar ratio of consonants and vowels (such as Hawaiian) would show a similar preference for making generalizations over vowels. At the same time, further studies with systematic variations of phonetic features may provide insights as to what information is more relevant for such differences to appear (e.g. Curtin et al., 2009).

Importantly, our results do not suggest it is impossible for infants to generalize structures over consonants. In fact, different roles of consonants and vowels have never been portrayed as an all-or-none phenomenon (see Nespor et al., 2003). That is, consonants may be involved in some cases of syntactic marking (as in the *liaison* in French) and vowels sometimes constrain lexical access (in minimal pairs such as *dog* and *dig*; see also Toro, Shukla et al., 2008). Empirical results have supported this conclusion, as adult participants have been shown to perform structural generalizations over consonants under very restrictive conditions, as when vowels are almost eliminated from the nonsense words during familiarization, and the number of participants is considerably increased (Toro, Shukla et al., 2008). In the same line, one may think that running three or four times as many infants in Experiment 2 may result in the slight difference in looking times between

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same and different trials required to reach statistical significance. However, as previously mentioned, our prediction was not that infants could not under any circumstance, generalize simple structures over consonants. Our hypothesis, supported by the current results, is that infants readily generalize such structures when implemented over vowels but not over consonants.

Two aspects of the stimuli used in the present study deserve further some considerations. First, studies on the generalization of simple rules (e.g. Johnson et al., 2009; Marcus et al., 1999), have usually compared the discrimination of structures containing repetitions (AAB, ABB, ABA). On the contrary, we have contrasted sequences containing the repetition of one of its elements (AAB) against sequences containing no repetitions (ABC). In fact, repetitions have been suggested to have a privileged status during the extraction of these types of regularities (see Endress, Dehaene-Lambert, & Mehler, 2007; Gervain, Macagno, Cogoi, Peña, & Mehler, 2008), so it may be the case they are playing a role in the discrimination reported in the present work. Nevertheless, it still remains the case that our results show that infants discriminated between the different structures when vowels were repeated and not when consonants were repeated. Once processing asymmetries between consonants and vowels are established at an early age, further work could explore more fine grain distinctions as those between sequences containing a repetition on their right (AAB) or on their left edge (ABB); or between sequences containing an adjacent repetition (AAB or ABB) or a non-adjacent one (ABA). Second, the nonsense words used in the present study had a CVCVCV structure. Is it possible that our results are explained by the position of consonants and vowels within such words? That is, is it possible that our results do not show any asymmetries between consonants and vowels, but just that infants readily generalize structures over elements in positions 2–4–6 in a given sequence, while they cannot generalize such structures over elements in position 1–3–5? Such an explanation is very unlikely. New and collaborators (2008) showed that the positions of consonants and vowels did not influence the effect they observed of stronger reliance on consonants for lexical access during a visual masked-priming task. That is, the relative role of consonants and vowels was not influenced by position within words (see also Carreiras, Duñabeitia, & Molinero, 2009, for a similar finding using electroencephalographic measures). Even more, one would need a principled explanation of why infants would easily perform generalizations over elements in positions 2, 4 and 6 in a sequence, but not over elements in positions 1, 3 and 5. No model of language processing makes this prediction, and experimental evidence runs against its plausibility. For example, a model based on left-to-right processing (as in cohort models) would assign processing primacy to consonants in our nonsense words. Yet, our results precisely show the opposite; that generalizations are difficult to make over these elements (see also Toro et al., 2008). In the same line, Endress, Scholl, and Mehler (2005) showed that elements in sequence edges are privileged in the extraction of similar structures, but found no advantage for either the initial or the final edge. In our case, both consonants and vowels are located in either edge of the sequence (the initial or the final edge), so no preference should be given to any of them. Using very similar stimuli, results have demonstrated that preference to perform structural generalizations over vowels is not linked to their salience (Toro, Shukla et al., 2008). Thus, there are no reasons to support the hypothesis that the specific structure of the words used in the present study affect the results observed.

Instead, results from this and other studies indicate that it is the different roles of consonants and vowels during language processing what most effectively explains differences in performance. The fact that infants are sensitive to such differences even before a lexicon is fully developed, suggests an early bias in language processing.

Acknowledgements

We are grateful to all of the parents and infants whose participation made this study possible. We thank Luca Bonatti and Nuria Sebastián-Gallés for valuable comments on earlier versions of this manuscript, and Anna Basora for her assistance. This work was supported by a Ramón y Cajal fellowship to JMT, and Consolider Ingenio 2010 CSD2007-00012 Grant from the Ministerio de Ciencia e Innovación.

References

Bonatti, L., Peña, M., Nespor, M., & Mehler, J. (2005). Linguistic constraints on statistical computations: The role of consonants and vowels in continuous speech processing. *Psychological Science, 16*, 451–459.

Bonatti, L., Peña, M., Nespor, M., & Mehler, J. (2007). On consonants, vowels, chicken and eggs. *Psychological Science, 18*, 924–925.

Bosch, L., & Sebastian-Galles, N. (2001). Evidence of early language discrimination abilities in infants from bilingual environments. *Infancy, 2*, 29–49.

Carreiras, M., Duñabeitia, J., & Molinero, N. (2009). Consonants and vowels contribute differently to visual word recognition: ERPs of relative position priming. *Cerebral Cortex, 19*, 2659–2670.

Curtin, S., Fennell, C., & Escudero, P. (2009). Weighting of vowels cues explains patterns of word-object associative learning. *Developmental Science, 12*, 725–731.

Cutler, A., Sebastián-Gallés, N., Soler-Vilageliu, O., & van Ooijen, B. (2000). Constrains of vowels and consonants on lexical selection: Cross-linguistic comparisons. *Memory & Cognition, 28*, 746–755.

Dutoit, T., Pagel, V., Pierret, N., Bataille, F., & van der Vrecken, O. (1996). *The MBROLA project: Towards a set of high-quality speech synthesizers free of use for non-commercial purposes*. Philadelphia: ICSLP.

Endress, A., Dehaene-Lambert, G., & Mehler, J. (2007). Perceptual constraints and the learnability of simple grammars. *Cognition, 105*, 577–614.

Endress, A., Scholl, B., & Mehler, J. (2005). The role of salience in the extraction of algebraic rules. *Journal of Experimental Psychology: General, 134*, 406–419.

Gervain, J., Macagno, F., Cogoi, S., Peña, M., & Mehler, J. (2008). The neonate brain detects speech structure. *Proceedings of the National Academy of Sciences, 105*, 14222–14227.

Havy, M., & Nazzi, T. (2009). Better processing of consonantal over vocalic information in word learning at 16 months of age. *Infancy, 14*, 439–456.

Johnson, S., Fernandes, K., Frank, M., Kirkham, N., Marcus, G., Rabagliati, H., et al. (2009). Abstract rule learning for visual sequences in 8- and 11-month-olds. *Infancy, 14*, 2–18.

Keidel, J., Jenison, R., Kluender, K., & Seidenberg, M. (2007). Does grammar constrain statistical learning? Commentary on Bonatti et al. (2005). *Psychological Science, 18*, 922–923.

Kolinsky, R., Lidji, P., Peretz, I., Besson, M., & Morais, J. (2009). Processing interactions between phonology and melody: Vowels sing but consonants speak. *Cognition, 112*, 1–20.

Kuhl, P., Stevens, E., Hayashi, A., Deguchi, T., Kiritani, S., & Iverson, P. (2006). Infants show a facilitation effect for native language phonetic

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perception between 6 and 12 months. *Developmental Science, 9*, F13–F21.

Kuhl, P. K., Williams, K. A., Lacerda, F., Stevens, K. N., & Lindblom, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science, 255*, 606–608.

Ladefoged, P. (2001). *Vowel and consonants: An introduction to the sounds of language*. Oxford: Blackwell.

Mani, N., & Plunkett, K. (2007). Phonological specificity of vowels and consonants in early lexical representations. *Journal of Memory and Language, 57*, 252–272.

Mani, N., & Plunkett, K. (2008). 14-month-olds pay attention to vowels in novel words. *Developmental Science, 11*, 53–59.

Marcus, G., Vijayan, S., Bandi Rao, S., & Vishton, P. (1999). Rule learning by seven-month-old infants. *Science, 283*, 77–80.

Narayan, C., Werker, J., & Beddor, P. (2010). The interaction between acoustic salience and language experience in developmental speech perception: Evidence from nasal place discrimination. *Developmental Science, 13*, 407–420.

Nazzi, T. (2005). Use of phonetic specificity during the acquisition of new words: Differences between consonants and vowels. *Cognition, 98*, 13–30.

Nazzi, T., Floccia, C., Moquet, B., & Butler, J. (2009). Bias for consonantal over vocalic information in French- and English-learning 30-month-olds: Crosslinguistic evidence in early word learning. *Journal of Experimental Child Psychology, 102*, 522–537.

Nespor, M., Peña, M., & Mehler, J. (2003). On the different roles of vowels and consonants in speech processing and language acquisition. *Lingue e Linguaggio, ii*, 201–227.

Nespor, M., & Vogel, I. (1986). *Prosodic phonology*. Dordrecht: Foris.

New, B., Araujo, V., & Nazzi, T. (2008). Differential processing of consonants and vowels in lexical access through reading. *Psychological Science, 19*, 1223–1227.

Owren, M., & Cardillo, G. (2006). The relative roles of vowels and consonants in discriminating talker identity versus word meaning. *Journal of the Acoustical Society of America, 119*, 1727–1739.

Saffran, J., Aslin, R., & Newport, E. (1996). Statistical learning by 8-month-old infants. *Science, 274*, 1926–1928.

Skoruppa, K., Pons, F., Christophe, A., Bosch, L., Dupoux, E., Sebastián-Gallés, N., et al. (2009). Language-specific stress perception by nine-month-old French and Spanish infants. *Developmental Science, 12*, 914–919.

Toro, J. M., Nespor, M., Mehler, J., & Bonatti, L. (2008). Finding words and rules in a speech stream: Functional differences between vowels and consonants. *Psychological Science, 19*, 137–144.

Toro, J. M., Shukla, M., Nespor, M., & Endress, A. (2008). The quest for generalizations over consonants: Asymmetries between consonants and vowels are not the by-product of acoustic differences. *Perception & Psychophysics, 70*, 1515–1525.

Werker, J. F., & Tees, R. C. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development, 7*, 49–63.

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