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Authors

Segal, Osnat
Keren-Portnoy, Tamar
Vihman, Marilyn

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Robust effects of stress on early lexical representation

Running head: word form recognition in infants

Abstract

This study aims to elucidate the factors that affect the robustness of word-form representations by exploring the relative influence of lexical stress and segmental identity (consonant versus vowel) on infant word recognition. Our main question was which changes to the words may go unnoticed and which may lead the words to be unrecognizable. One-hundred 11-month-old Hebrew-learning infants were tested in two experiments using the Central Fixation Procedure. In Experiment 1, 20 infants were presented with iambic Familiar and Unfamiliar words. The infants listened longer to Familiar than to Unfamiliar words, indicating their recognition of frequently heard word forms. In Experiment 2 four groups of 20 infants each were tested in each of four conditions involving altered iambic Familiar words contrasted with iambic Unfamiliar nonwords. In each condition one segment in the Familiar word was changed – either a consonant or a vowel, in either the first (unstressed) or the second (stressed) syllable. In each condition recognition of the Familiar words despite the change indicates a less accurate or less well-specified representation. Infants recognized Familiar words despite changes to the weak (first) syllable, regardless of whether the change involved a consonant or a vowel (conditions 2a, 2c). However, a change of either consonant or vowel in the stressed (second) syllable blocked word recognition (conditions 2b, 2d). These findings support the proposal that stress pattern plays a key role in early word representation, regardless of segmental identity.

Introduction

Word comprehension can be demonstrated experimentally as early as 6-9 months, although the findings are largely limited to common nouns (Bergelson & Swingley, 2012, 2015; Tincoff & Jusczyk, 1999, 2012); an increase in the rate of word learning has been shown from about 14 months. At the same time, as Swingley (2007) argued, the FORMS of many frequently heard words are recognized before any meaning becomes attached to them. Testing infants, without providing experimental training, on words used often in everyday speech has shown that by 11 months their long-term memory for or knowledge of a few such word forms is sufficient to hold their attention as a list is played to them, indicating ‘preference’ or ‘word form recognition’, while unfamiliar or rare words arouse significantly less interest (Hallé & Boysson-Bardies, 1994; Swingley, 2005; Vihman & Majorano, 2017; Vihman, Nakai, DePaolis & Hallé, 2004; Vihman, Thierry, Lum, Keren-Portnoy & Martin, 2007).

What requires further investigation is the quality of the long-term memory representations that support such early word-form recognition or, more specifically, how complete or fully specified those representations may be. This study is designed to fill two important gaps in our understanding in this area, regarding the effect on the quality of representations of (i) prosodic salience (accented or stressed vs. unaccented or unstressed syllables) and (ii) segment types (consonants vs. vowels).

In an influential study Hallé and Boysson-Bardies (1994) opened this line of investigation into the robustness of infants’ representations of word forms that could be expected to be familiar from every-day exposure. They and others who followed

them found that by 11 months infants learning French, English, Dutch and Italian show a preference for word forms to which they have been exposed in their daily life (Familiar words, e.g., /*bonjour*/ 'hello') over Rare words with similar forms (e.g., /*caduc*/ 'obsolete') that they are unlikely to have ever heard (Hallé & Boysson-Bardies, 1994; Swingley, 2005; Vihman et al., 2004).¹ In addition, infants seem to disregard some single-segment changes to such words, which continue to be 'recognised', while other changes lead the words to become indistinguishable from unfamiliar words.

In French, changes to the onset consonant of the second, accented syllable of the word was found to block recognition while changes to the onset consonant of the first, unaccented syllable did not (Hallé & Boysson-Bardies, 1996). The authors suggested that segmental representation may be flexible in infants of this age, at least in unaccented or weak syllables. This view was corroborated by findings from English, in which the typical stress pattern is trochaic (i.e., stressed on the first syllable, in the case of a disyllabic word). In English, changes to the onset of the FIRST syllable, which is stressed, blocks recognition, but changes to the onset of the second, unstressed syllable does not (Vihman et al., 2004; see also Delle Luche, Floccia, Granjon & Nazzi, 2017). Similarly, Swingley found that, for Dutch, changes to the onset of a monosyllable blocks recognition, while changes to the coda does so to a lesser extent. Together these three studies suggest that infants may represent some parts of words relatively strictly while they represent other parts (unaccented syllables or codas) less so, such that changes affecting those parts are insufficient to block recognition. (Note that in each of these studies a failure to recognise familiar words

¹ We capitalise *Familiar* and *Rare* in reference to contrasting sets of stimuli.

despite changes to them is a sign of a robust or more mature representation, whereas successful recognition of familiar words despite any alterations signals a less robust or less strict, perhaps less well specified and less mature representation.)

Another issue touching on the robustness or inflexibility of the segmental makeup of word-form representations is the possibility that different classes of segments may be differently represented. Poltrock and Nazzi (2015) tested the effects of altering the vowel vs. the consonant of the accented (final) syllable in French. Infants recognised words despite changes to the vowel but not to the consonant. Their results fit with the proposal set forth by Nespor, Peña and Mehler (2003), that consonants are more essential than vowels for word recognition. Nespor et al.'s predictions were not borne out in all the languages tested, however, which led other researchers to claim that the relative importance of vowels or consonants for word identification derives from the lexical and phonological characteristics of particular languages rather than being a universal principle (Floccia, Nazzi, Delle Luche, Poltrock & Goslin, 2014; Højen & Nazzi, 2016). Thus, while it has now been established that there may be a difference in the strictness of infant word-form representation of vowels and consonants, it remains an open question to what extent such a difference manifests itself in different languages.

Similarly, we question whether the findings regarding the relative robustness of the representations of weak (unaccented, unstressed syllables, codas) and strong elements (accented, stressed syllables, onsets) should be taken to be universal. Arguably, this may be warranted, since stress, to some extent, involves directly measurable characteristics, such as size of articulatory gesture or duration. However,

the apparent mirror-image characteristic of the French and English results (Vihman et al., 2004) hides a subtle difference: When the alteration affected the UNSTRESSED syllable, infants learning both languages recognized Familiar words despite consonant changes to the syllable onset. When the change affected the stressed or accented syllable, in contrast, the blocking effect was quite weak in French,² whereas the English results were straight-forward, showing clear blocking of recognition.

As Vihman et al. (2004) note, the difference in the effect of changes to the accented syllable in English as compared with French could be ascribed to one of two factors: (i) The nature of ‘accent’ differs in the two languages in important ways: French accent is not associated, as in English, with increases in pitch or amplitude but rather with vowel lengthening, which furthermore affects only the final syllable of a phrase, not the word. Thus words are marked for accent only when they are phrase-final, giving infants less exposure to the accentual pattern. (ii) Word-initial consonants have a privileged status in lexical processing (Allopenna, Magnuson, & Tanenhaus, 1998; Marslen-Wilson, 1987). Thus, in English the initial syllable is not only strongly stressed but also the first to be encountered in processing, whereas in French the two syllables participate in a trade-off, with a processing advantage for the first syllable and an accentual salience advantage for the second. Either of these factors might account for the difference in Vihman et al.’s (2004) findings for French as compared with English. Only by testing a language with contrastive iambic lexical stress, in which the non-initial syllable is generally stronger, can we establish whether infant

² In an initial analysis the French infants showed recognition for the Familiar words despite alteration to the onset of the accented syllable. Only after an outlier was removed did the group results show blocking of recognition.

responses are influenced more by accentual salience or by the order in which auditory stimuli are processed.

Fortunately, Modern Hebrew can serve as a good test of both the issues at hand – the effects of stress and word position on the robustness of representation, and the strictness of the representation of consonants as compared with vowels. Hebrew has strong lexical stress, which is most typically iambic (about 70% of all content words in child-directed speech, or CDS), but also includes trochaic words (only 30% of content words, but about 40% of all nouns in CDS) (Segal, Nir-Sagiv, Kishon-Rabin & Ravid, 2009). Weak syllables do not differ from stressed syllables in vowel quality in Hebrew (there is no vowel reduction) and the acoustic correlates of stress include duration, pitch and amplitude (Bolozky, 1982; Bolozky, 2000; Silber-Varod, Sagi & Amir, 2016). Thus for the infant learner, Hebrew, with its strong lexical stress and preponderance of iambic disyllabic words, is closer to a ‘mirror-image’ of English, with its mostly trochaic disyllabic pattern, than is French, which lacks lexical stress. Therefore, investigating infant memory for Hebrew iambic words can help to disentangle the effect of stress from that of word position, since in Hebrew, unlike English, the part of the word that is stressed is not the initial syllable.

Hebrew differs in important ways from both English and French. The morphological system, like that of Semitic languages in general, is based on the interleaving of phonological patterns (consisting mainly of vowels) and consonantal roots. Word formation requires the combination of a root with a phonological pattern and a fixed stress. The root, which usually consists of three consonants, expresses the semantic core of the word (Berman, 1987; Ravid, 1990; we represent it in the

examples below as triconsonantal sequences [C...C...C]). There are distinct vowel-and-stress patterns for nouns and adjectives (termed *mishkalim*) and for verbs (*binyanim*). Thus, many open-class words share a vowel-and-stress pattern but differ in their consonants across the word (e.g., the common noun and adjective pattern Ca 'CoC consists of three root consonants interleaved with the vowels /a...o/, with stress on the second syllable: /ga'dol/ 'big', /ka'ʁov/ 'near', /la'ʃon/ 'tongue', /ʃa'lom/ 'peace, hello').

The vowel pattern is essential for recognizing a word's lexical class and/or semantic field. For example, a subclass of the pattern illustrated above denotes colour names (e.g., /ka'χol/ 'blue', /ʔa'dom/ 'red', /ja'ʁok/ 'green', etc.). Another pattern, Ca 'CeCet, indicates, among other things, names of diseases (e.g., /ka'levet 'rabies', /ʃa'ʔelet/ 'whooping cough', /ʔsa'ʁevet/ 'heartburn', etc.). The consonantal root, which denotes the semantic core of words (e.g., l-m-d 'related to learning'), is associated with different vowel patterns (e.g., /la'mad/ '(he) studied', /li'med/ '(he) taught', /tal'mid/ 'student', /tal'mud/ 'Talmud').

This clear division of labour between vowels, which define possible word forms and constrain parts of speech and sometimes semantic fields, and consonants, which define the semantic core, is in accord with Nespor et al.'s (2003) 'CV hypothesis', which indeed was formulated with Semitic languages in mind. According to this hypothesis, consonants universally contribute more to lexical identification than vowels, whereas the key role of vowels is in marking prosodic and morphosyntactic aspects. Although Nespor et al.'s analysis of the different roles of consonants and vowels fits with their roles in Hebrew, these authors' predictions

regarding word identification do not. We argue that the morphological structure of Hebrew gives rise, instead, to the prediction that *both vowels and consonants* should be important for word recognition and representation for Hebrew learners: While different words belonging to the same pattern are differentiated only by their consonants, different words belonging to the same root are differentiated only by their vowel pattern.³ A nonword in Hebrew can result from the combination of a non-existent root with an existent pattern, an existent root with a non-existent pattern, or an existent root with an existent pattern to create a possible but unattested lexical item. In each case it is only the combination of the root and pattern that will allow a listener to judge if an item is a word or not. Hebrew speakers are sensitive to vowel sequences (or patterns) as defining ‘wordlikeness’ and even word class, possible semantic field, noun gender and number as well as gender, person, tense and mood in the case of verbs. This sensitivity can be gauged, for example, from the productivity of different verb patterns (Schwarzwald, 1996), and from experiments in which participants derive new verbs, adjectives or nouns, fitting them into particular patterns – some of which denote quite narrow semantic fields (Bolozky, 2007, for adults; Berman, 2003, for children, for verbs only). Indeed, already at 11 months infants learning Hebrew recognize common vocalic patterns and prefer listening to common than to rare or non-occurring patterns (Segal, Keren-Portnoy, & Vihman, 2015).

³ Loan words are often easily identifiable due to the fact that neither their stress or vowel pattern nor the number of consonant slots adheres to any of the well attested Hebrew patterns. Hebrew speakers implicitly exhibit sensitivity to this by treating such loan words differently from native words (the stress of their plural form is not shifted to the final syllable, for instance, as it would be in native words).

The purpose of the present study is to assess the influence of both stress and segment type (vowels vs. consonants) on the representation of familiar iambic words in the long-term memory of infants learning Hebrew. If we find that the representation of Hebrew iambic words is more robust in the stronger than in the weak syllable, this will support the suggestion that representation is influenced by accentual salience (Vihman et al., 2004). In addition, if the representation of consonants proves more critical for word recognition than the representation of vowels, this will support the CV hypothesis (Nespor et al., 2003), which argues for a universal difference in the relative roles of vowels and consonants. If, however, we fail to find primacy for consonants over vowels, that will support the claim that the difference in the roles of consonants and vowels as regards word recognition is due to language-internal phonological and lexical characteristics (e.g., Floccia et al., 2014; Højen & Nazzi, 2016; Mani & Plunkett, 2007, 2010).

Experiment 1

This experiment served as a baseline. It was designed to determine whether, at 11 months, infants learning Hebrew, like children learning French (Halle and Boysson-Bardies, 1994), English (Vihman et al., 2004), Dutch (Swingley, 2005) or Italian (Vihman & Majorano, 2017), would respond with greater attention to lexical items familiar from their everyday experience than to unfamiliar lexical items, without specific training in the lab.

Methods

The Central fixation procedure was used (Cooper & Aslin, 1990). The procedure is based on the assumption that infants tend to orient their look towards a

sound source and attend differently to auditory stimuli they recognize from the way they attend to auditory stimuli they do not recognize. Based on past research, we expected longer looks to the Familiar than to the Unfamiliar stimuli (described below).

Participants

The participants were 20 healthy monolingual Hebrew-learning 11-month-old infants (12 boys). One additional infant was excluded because of fussiness. The infants' ages ranged from 10;11 (months; days) to 11;20 ($M = 10;29$, $SD = .42$). Inclusion criteria were as follows: (1) full-term, (2) normal development and hearing as reported in response to a developmental questionnaire developed by Segal and Kishon-Rabin, (3) score within 2 standard errors (SE) of normal auditory and production functioning on the Infant Toddler Meaningful Auditory Integration Scale (ITMAIS) (Robbins, Koch, Osberger, Zimmerman-Phillips, & Kishon-Rabin, 2004) and Production Infant Scale Evaluation (PRISE) (Kishon-Rabin, Taitelbaum-Swead, Ezrati-Vinacour, & Hildesheimer, 2005; Kishon-Rabin, Taitelbaum-Swead & Segal, 2009),⁴ and (4) parental report of no more than two ear infections during the last 6 months and no upper respiratory infections (including ear infections) in the last two weeks. Infants were recruited via advertisements on the internet. Families were paid a small fee for their participation.

Stimuli

The stimuli included two lists of disyllabic iambic (weak-strong) words, Familiar and Unfamiliar. Each list contained 14 words. The Familiar words were

⁴ No infant was excluded due to low scores on either of these tests.

frequent in CDS, based on the Berman longitudinal corpus (Berman & Weissenborn, 1991) in CHILDES (Mac-Whinney, 2008),⁵ and were chosen from among the 101 most frequent disyllabic words (both closed and open class) spoken by parents to their children. Out of these we chose only words that have (1) weak-strong stress, (2) consonantal onsets to both syllables (in spoken language) and (3) singleton onset to the first syllable. In addition, because Hebrew marks gender on verbs, nouns and adjectives, we chose either gender-neutral forms (e.g., /ʃe'li/ 'mine') or, in the case of the word 'want.PR.SG', the masculine form /ʔo'tse/ with male participants and the feminine form /ʔo'tsa/ with female participants. Forms marked for gender were included only if, in our judgment, they are not typically used primarily to refer to the child, so that familiarity with them is not dependent on the child's gender. The Unfamiliar words had an occurrence in texts of less than .002 percent (Frost & Plaut, 2001). All but one of the Familiar words were paired with an Unfamiliar word with the same vowel pattern, so that any differences in looking times could not be due to vowel pattern differences (see Appendix B for the word lists).⁶

Stimuli were digitally recorded in a soundproof room via a JVC MV 40 microphone using Sound-Forge software (version 4.5a) and stereo channels at a

⁵ The CDS in this corpus included 228,948 word tokens (68,006 bi-syllabic words) recorded longitudinally over a total of 392 sessions, one hour per week, at the homes of four middle-class children, aged 1;5–3 years (3 girls) (Berman Longitudinal corpus, CHILDES, Mac-Whinney, 2008).

⁶ The word /bu'ba/ was paired with /ni'na/, which has a different first-syllable vowel. We deemed it more important to ensure that a similar number of words in the two lists have consonant harmony than to maintain the vowel pattern match. More generally, we controlled for the vowel sequences in the actual form of the words we used rather than for what grammarians of Hebrew consider the historical vowel patterns (e.g., /na'xon/ 'right, correct' is traditionally considered to belong to the pattern *niCCaC*, but due to its 'weak' root (i.e., a root containing the glide /w/), its form contains the vowel sequence a – o, not i – a. Because infants cannot be expected to know the historical roots or vowel patterns, we classify this word as an a – o word.

sampling rate of 48,000 Hz and 16-bit quantisation level. A single token was used for each word. To prevent intensity differences between words, amplitudes were normalized. The two lists did not differ in terms of the words' mean duration (Familiar: 558.64 msec, $SD = 108.23$, Unfamiliar, 580.93 msec, $SD = 93.47$, two-tailed test, differences ns, $p = .60$). Additional data regarding fundamental frequency and duration are shown in Appendix A. Sixteen audio files were created from the 28 tokens, eight audio files of Familiar words and eight of Unfamiliar words. Each audio file had a different internal word order, randomly determined, with 500-msec silent inter-token intervals. The mean duration of the final audio files was 15.53 sec, $SD = .09$ (range 15.32-15.61 sec) for the Familiar lists and 15.23 sec, $SD = .06$ (range 15.52-15.57 sec) for the Unfamiliar words (two-tailed test, differences ns, $p = .78$).

Apparatus

The test took place in a sound-proof booth next to a control room (as described in Segal et al., 2015). The booth included a large 50" wide-aspect TV monitor with two loudspeakers attached to each side, and a video camera fixed above the monitor. The camera recorded the orientation of the infant's eyes; the experimenter viewed the infant via a video monitor located in the control room. Grey curtains hung from the ceiling to reduce distractions and block the infant's view of the rest of the room. The control room included a 23" monitor for observing the infant's responses and a Macintosh G5 personal computer that presented the auditory stimuli to the loudspeakers through an amplifier. The experiments were controlled by the computer (including presentation of the trials and recording of the infant's response), using HABIT (Cohen, Atkinson & Chaput, 2000).

Procedure

The infant sat on the caregiver's lap in front of the monitor. Both caregiver and experimenter listened to music overlaid with masking babble noise over headphones and were therefore unaware of the type of stimulus played on any trial. All trials began by drawing the infant's attention to the TV monitor, using an attention getter (e.g., a small dynamic video display of a laughing baby face: see Houston, Pisoni, Kirk, Ying & Miyamoto, 2003; Segal & Kishon-Rabin, 2011). Stimuli were presented to the infants via loudspeakers at a comfortable level (65 dB SPL). Each infant first completed a four-trial familiarisation phase. This phase consisted of two trials of each type (Familiar and Unfamiliar), in order to familiarise the infants with the procedure (following Vihman et al., 2004). After the familiarisation phase a 12-trial test phase was conducted. The order of presentation of the files was pseudo-random, with no more than two trials of the same type in a row. During the trials, a visual display (red and white static checkerboard) was presented on the TV monitor. Each trial continued until the infant looked away for 2 seconds or more or until the end of the trial. If the infants looked away for less than 2 seconds, the trial continued, but the time looking away was not included in the length of look. The experimenter in the control room observed the infant via a monitor and coded the duration of the infants' gaze toward the visual display by pressing keys on the computer keyboard.

All infant responses were videotaped for later offline validation by a second experimenter. Offline measures for each test trial were conducted by a graduate student from the Communication Disorders Department BLINDED FOR REVIEW, who measured infant looking times on the basis of frame-by-frame observation using

the digitised video software Supercoder (frame rate = 1/30 sec). The offline coder could not hear the stimuli and was naïve to the purpose of the study. Online and offline mean looking times to Familiar and Unfamiliar words were calculated for each infant. Convincing agreement was found between the online and offline mean measurements for both the Familiar ($r = .97$) and the Unfamiliar ($r = .96$) trials. The online looking times were used for further statistical analysis. The procedure was approved by the Helsinki ethical committee, Ministry of Health, BLINDED FOR .REVIEW, and by the ethical committee of BLINDED FOR REVIEW

Results and discussion

A normality test (Kolmogorov-Smirnov) confirmed that looking times were normally distributed. A two-tailed paired t-test shows that looking times were significantly longer in response to Familiar ($M = 5.27$; $SD = 2.56$) than to Unfamiliar ($M = 3.55$; $SD = 1.78$) trials ($t(19) = 5.12$, $p = .005$; Cohen's $d = 1.62$). See Figure 1: Differences above the 0 line indicate longer looks to the Familiar than to the Unfamiliar list. Individual data showed a preference for Familiar trials for all but one infant (95%) (binomial test, $p < .001$), as can be seen in the figure, which shows that in almost all cases the difference in looking times is positive (i.e., longer looks to the Familiar list).

PLEASE INSERT FIGURE 1 HERE

The results of Experiment 1 show that 11-month-old infants learning Hebrew listen longer to Familiar than to Unfamiliar words, as do 11-month-old infants learning French (Hallé & Boysson-Bardies, 1994), English (Vihman et al., 2004), Dutch (Swingley, 2005) and Italian (Vihman & Majorano, 2017). Given that 11-

month-old infants acquiring Hebrew show familiarity with word forms that they hear frequently in their daily lives, we can now ask how stress affects the representation of familiar words. Experiment 2 was designed to assess representation of both weak and strong syllables, as regards both consonants and vowels.

Experiment 2

The second experiment was designed to separately assess the representation of consonants and vowels in the weak (first) and the strong (second) syllables. We reasoned that if the representation of the consonants and vowels in each syllable is crucial for word recognition, we could expect a change to either segment type to affect recognition (leading to no preference for Familiar over Unfamiliar words). However, if the representation of the consonants and vowels is mediated by the position of the segment relative to stress, then infants may recognize the Familiar words despite the change only when that change affects the unstressed, not the stressed syllable. We also wanted to assess whether consonants and vowels may affect representations differently. We reasoned that if the representation of the consonants and vowels is similar, changes to either consonants or vowels should have similar effects, leading to no preference for Familiar over Unfamiliar words. However, if the representation of consonants is more robust compared to vowels, then infants may recognize the Familiar altered words only when the change affects the vowels, not the consonants.

The second experiment included four test conditions, each of which involved comparing the list of Familiar words, each with a single altered consonant, to nonwords. The alterations were to: a) the first consonant of the first, unstressed syllable (Altered C1: condition 2a), b) the first consonant of the second, stressed

syllable (Altered C2: condition 2b), c) the vowel of the first, unstressed syllable (Altered V1: condition 2c), and d) the vowel of the second, stressed syllable (Altered V2: condition 2d).

Participants

A total of 80 full-term monolingual Hebrew-learning infants participated in the present study, 20 in each test condition. The mean and range of ages for each test condition are described in Table 1. An additional nine infants (11 %) were excluded from the study because of crying (1) and fussiness (8). Inclusion criteria, recruitment methods, and payments to participants were the same as for Experiment 1. A one-way ANOVA with age as the dependent variable and test condition as the independent variable revealed no significant difference between infant ages in the different conditions [$F(3, 76) = 2.55, p = .06$].⁷

[PLEASE INSERT TABLE 1 HERE]

Stimuli

The 14 Familiar words used in Experiment 1 were changed by altering a single segment to create stimuli for the four test conditions. Additional nonwords were created for each test condition, based on the Unfamiliar words from Experiment 1. The stimuli for each test condition and the changes involved relative to the Familiar list are presented in Appendix B.

⁷ In addition, to ensure that the slight differences in mean ages between the different groups do not explain different looking preferences, we calculated the preference for Familiar over Unfamiliar nonwords for each infant, measured as a difference score between their mean looking times to each type of stimulus. No correlation was found between age and preference score in any of the four groups of infants (all $ps > .05$).

In test conditions 2a and 2b one consonant of the Familiar words was modified, generally by a single place or manner feature. (In three [condition 2a] or four cases [2b] two features had to be changed, either due to restrictions on possible feature combinations in Hebrew or because single-feature changes would result in potentially familiar or offensive words.) In test conditions 2c and 2d changing the vowels of the Familiar words changed the patterns that the words were associated with and thus created words with possible consonantal roots (as we had not changed the consonants) but, in many cases, with unattested or infrequent vowel sequences or, in essence, less ‘wordlike’ words. In both cases, Unfamiliar words had to be changed more radically. Because Hebrew makes heavy use of a limited set of patterns, many of the Unfamiliar words used in Experiment 1 were lexical neighbours of words that might be familiar to the infants, differing from them by a single segment. Changing a single segment, consonant or vowel, would not necessarily mitigate this problem. We therefore created a set of nonwords from the Unfamiliar words used in Experiment 1. While maintaining the vocalic pattern of the parallel Altered Familiar words, we continued to make consonantal changes until we judged that no single segment change could turn the nonword into a word likely to be familiar to infants. A few of the Altered Familiar words or Unfamiliar nonwords are real but rare words.⁸ We will refer to these too as Altered Familiar words or as Unfamiliar nonwords). For all test conditions the Altered Familiar word list was paired with an Unfamiliar nonword list

⁸ One is a Biblical place name, others are nouns or verbs, some of them inflected for possession or with a cliticised preposition. The following number of such cases are found in each experiment: two among the Altered C1 Familiar words and three among the Altered C1 Unfamiliar nonwords in Experiment 2a; two among the Altered C2 Familiar words and one among the Altered C2 Unfamiliar nonwords in Experiment 2b; two among the Altered V1 Familiar words and four among the Altered V1 Unfamiliar nonwords in Experiment 2c; two among the Altered V2 Familiar words and six among the Altered V2 Unfamiliar nonwords in Experiment 2d

with identical vowel sequences and with comparable consonantal makeup. We also attempted, as far as possible, to use consonants with similar places and manners of articulation in each Altered Familiar-Unfamiliar list pair, so the lists would not differ simply by virtue of their consonant types. (For the Altered Familiar and Unfamiliar lists and changes relative to the unaltered Familiar words, see Appendix B. For the balance in consonantal makeup between the Altered Familiar and Unfamiliar nonwords see Appendix C).

All stimuli were recorded and normalized and stimulus files created as for Experiment 1. The mean duration, frequency and amplitude of the Altered Familiar words and Unfamiliar nonwords for each test condition are shown in Table A1 in Appendix A. The mean durations of the final audio files are presented in Table A2 in Appendix A. The Altered Familiar and Unfamiliar nonwords did not differ significantly on any of the measures.

Apparatus and procedure

The apparatus and procedure were identical to those used in Experiment 1. Offline measures for each test trial were conducted similarly to Experiment 1. Agreement between the online and offline looking time measurements for Familiar trials was $r = .95, 0.96, 0.98,$ and 0.95 for the Altered C1, Altered C2, Altered V1, and Altered V2 conditions, respectively. Agreement between the online and offline looking time measurements for Unfamiliar nonwords was $r = .94, 0.97, 0.96,$ and 0.96 for the Altered C1, Altered C2, Altered V1, and Altered V2 conditions, respectively.

Results

The results for each infant in the four test conditions are shown in Figure 2. In condition 2a (with altered consonant in the weak syllable) 17 out of 20 infants (85%) looked longer to the Altered C1 Familiar words than to the Unfamiliar nonwords (binomial test, $p = 0.01$: See Figure 2, which shows that the majority of values are above 0), but in condition 2b (with altered consonant in the strong syllable) only 10 out of 20 infants (50 %) showed a preference for the Altered C2 Familiar words over the Altered C2 Unfamiliar nonwords (binomial test $p = 1.00$: the distribution is centred around 0 in Figure 2). Similarly, in condition 2c (with altered vowel in the weak syllable) 15 out of 20 infants (75%) looked longer to the Altered V1 Familiar words than to the Altered V1 Unfamiliar nonwords (binomial test, $p = .04$: The majority of values are above 0 in Figure 2), whereas in condition 2d (with altered vowel in the strong syllable) only 9 out of 20 infants (45%) showed a preference for the Altered V2 familiar words over the Altered V2 Unfamiliar nonwords (binomial test, $p = 0.82$: Again, the distribution is more or less centred around 0).

PLEASE INSERT FIGURE 2 HERE

Looking times to each of the Familiar and Unfamiliar nonword lists in each of the four test conditions were normally distributed (Kolmogorov-Smirnov). A three-way mixed ANOVA across test conditions was performed with Familiarity as within-subject variable (Familiar Altered vs. Unfamiliar nonwords) and Altered syllable (weak vs. strong) and Type of change (consonant vs. vowel) as between-subject variables. The results show a main effect of Familiarity [$F(1,76) = 7.58, p = .007, \eta^2 = .09$], with longer average listening time for Altered Familiar ($M = 4.92, SE = .23$) than for Unfamiliar nonwords ($M = 4.33, SE = .20$). A main effect was also found for

Syllable [$F(1,76) = 7.33, p = .008, \eta^2 = .09$], with longer overall average looking time when the change was in the second, strong syllable ($M = 5.14, SE = .26$) compared to the first, weak syllable ($M = 4.12, SE = .26$).⁹ No main effect was found for Type of change (consonant vs. vowel) [$F(1,76) = 1.08, p > .05, \eta^2 = .01$]. The interaction between Familiarity and Condition was also significant [$F(1,76) = 6.11, p = .016, \eta^2 = .07$]. No other interaction was significant.

The source of the interaction (Familiarity and Condition) was assessed using pairwise comparisons with Bonferroni corrections. The results show that when the change was in the strong (second) syllable, no significant difference was found between looking time to Altered Familiar words ($M = 5.17, SE = 0.32$) and Unfamiliar nonwords ($M = 5.11, SE = 0.29$) ($p = .84$). However, when the change was in the weak (first) syllable, looking time was longer for Altered Familiar words ($M = 4.68, SE = .32$) than for Unfamiliar nonwords ($M = 3.56, SE = .29$) ($p = .0001$). Type of change did not significantly interact with Familiarity and Altered Syllable. However, given our a priori interest in potential differences between consonants and vowels, we also tested this separately for each type of change. The difference between Altered Familiar and Unfamiliar nonwords, when the alteration affected the weak syllable, was found for both consonants ($M = 4.40, 3.22, SE = 0.42, 0.49$ for Altered Familiar and Unfamiliar nonwords, respectively, $p = .006$) and vowels ($M = 4.96, 3.91, SE = 0.49, 0.45$ for Altered Familiar and Unfamiliar nonwords, respectively, $p = .002$), as shown in Figure 2. As mentioned above, ‘recognising’ the altered words is actually a

⁹ This is an interesting finding, orthogonal to the issue under investigation: The longer looking times suggest that when the change affected the stressed syllable the infants found the task itself more engaging or challenging, although they did not look longer to the altered Familiar than to the Unfamiliar stimuli.

sign of less mature or overly flexible representations, whereas not recognising them (and therefore showing no difference in looking time to Familiar over Unfamiliar stimuli) is a sign of more robust representations. The pattern of results therefore indicates more robust representations for the stressed than for the unstressed syllable.

General Discussion

In the present study 11-month-old infants learning Hebrew were found to recognize Familiar words even when the unstressed (first) syllable was altered and regardless of whether the change involved a consonant (Exp. 2a) or a vowel (Exp. 2c). However, a change of either consonant (Exp. 2b) or vowel (Exp. 2d) in the stressed (second) syllable blocked word recognition. These findings support the suggestion that stress pattern plays a crucial role in early word representation. On the other hand, they do not indicate a processing advantage for the first syllable. Furthermore, the relative prosodic prominence of the syllable (weak or strong) was seen to influence representation beyond segment type, consonant or vowel. In what follows we elaborate on these findings in the light of existing theories of word representation and recognition.

The present study is the first to show that in Hebrew, a language with strong lexical stress, stress influences early infant word representation. Previous findings comparing English with French indicated differences in infant sensitivity to different parts of the word (Hallé & Boysson-Bardies, 1996; Vihman et al., 2004). However, because of the differences in the nature of accent in these two languages it was not possible to establish whether this finding was due to (i) the representation being more robust for the syllable that is accented or (ii) the privileged processing order of the

first syllable rendering it more critical for word identification, regardless of stress position. In short, French is not a mirror image of English; Hebrew provides a much closer analogue, being a language, like English, with strong lexical stress, but in which lexical stress, in contrast to English, most often falls on the final syllable. That makes Hebrew a good test-case for pitting the effects of stress against those of primacy.

The present findings are important for models of word recognition. The cohort model has long suggested that the onset of a word activates a set of similar words, or cohort, which compete for recognition. The activation of irrelevant members then decreases as additional information is processed. Thus, according to this model, word onset is a crucial cue for lexical access and word recognition is described as a sequential process (e.g., Allopenna et al., 1998; Marslen-Wilson, 1987; Marslen-Wilson & Welsh, 1978). The TRACE model (McClelland & Elman, 1986) also assumes sequential lexical processing but allows for other parts of the word to activate lexical candidates as well. Our study fails to provide additional support for these models.

In contrast to continuous mapping models or, in other words, models (like TRACE) that see lexical identification as proceeding segment by segment, prosodic models of word recognition assume that lexical activation need not always proceed sequentially; they suggest instead that non-initial stressed syllables may initiate lexical search and retroactive processing. Thus, possible ambiguity in the first, weak syllable can be resolved based on information in the more salient part of the word (Cutler & Norris, 1988; Luce & Cluff, 1998; Mattys & Samuel, 2000; Shillcock,

1990). According to prosodic models, the stressed syllable plays a crucial role in representation due to its salience, regardless of whether or not it is word-initial (Mattys & Samuel, 2000). The findings of the present study support this view, showing that the stressed syllable is particularly informative for infant word recognition, at least in languages with lexical stress.

Furthermore, findings on child word production in Hebrew provide additional evidence that the stressed syllable has special importance. The first attempts at either iambic or trochaic words typically start with production of the stressed syllable (Ben-David, 2001; Ben-David & Berman, 2007). Also, in a case study described in Keren-Portnoy and Segal (2016) the word-initial consonant in the unstressed first syllable of iambic words is frequently omitted; in contrast, the onset consonant tends to be preserved in trochaic words, in which it is part of the stressed syllable.

The present study shows that, in Hebrew, vowels and consonants must be taken to be equally important for infant word identification, as changes to either consonants or vowels block recognition when they affect the stressed syllable. Thus Nespor et al.'s 2003 prediction was not corroborated in our study. Our findings have implications for the role of consonants and vowels in early word representation. While studies with infants learning French or Italian have supported the idea that consonants are more important than vowels for lexical recognition (Havy & Nazzi, 2009; Nazzi, 2005; Nazzi & Bertoncini, 2009; Nazzi, Floccia, Moquet & Butler, 2009; Nazzi & New, 2007; Poltrock & Nazzi, 2015), studies with infants learning English (Floccia et al., 2014, Mani & Plunkett, 2007, 2010) or Danish (Højen & Nazzi, 2016) have not. Importantly, these contrasting findings mean that the relative importance of vowels

and consonants for lexical recognition is a matter not of universal biases but of their relative informativeness in a given language. Aspects of informativeness which have been found to affect lexical recognition are, for example, which of the two categories is the larger and less-often lenited or elided (Højen & Nazzi, 2016), which of them contributes the most unique combinations to the lexicon (Keidel, Jenison, Kluender & Seidenberg, 2007), and how similar early-learned words are to one another and therefore how beneficial it is to attend to only one type of segment rather than to both (Floccia et al., 2014; Højen & Nazzi, 2016). In addition, Semitic word structure assigns crucial roles to both consonants and vowels, which means that speakers and listeners need to consider both consonants (which identify the root) and vowels (which identify the pattern) to distinguish between different real or potential words and to judge wordlikeness. Indeed, we have shown elsewhere (Segal et al., 2015) that 11-month-old infants already show familiarity with common vocalic patterns in Hebrew. The infants ‘recognised’ the patterns, exemplified through the use of nonwords containing unattested roots (or consonant sequences), in spite of their lack of familiarity with the consonant sequences embedded in them. However, that study did not test whether infants would ‘recognise’ existent consonant sequences with unattested vowel sequences (i.e., existent roots with unattested patterns). Thus, although the study showed that, for Hebrew-learning infants, vowels contribute a sense of word familiarity (and presumably eventually contribute to word recognition), it did not show that vowels trump consonants in that respect.

Finally, we find that word identification depends on the stressed syllable, with consonants and vowels both playing a role; however, within the unstressed syllable neither segment type plays a crucial role. Our findings show that neither vowels nor

consonants are uniformly criterial even within a given language, since here word recognition was either blocked or not, depending on accentual position; the differences in segment type affected by the experimental changes proved irrelevant.

Perhaps one of the most important lessons from this study, when taken together with the previous findings, is that what may be critical for word recognition in one language may be irrelevant for another, due to differences in stress systems or relative size of vowel and consonant inventories, or possibly other factors. The more languages are investigated, the more likely we are to find cross-linguistic variation in the units infants represent the most robustly in their early word forms.

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