A role for incidental auditory learning in auditory-visual word learning among kindergarten children

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This study focused on the potential role of incidental, auditory perceptual learning in among children learning new words. To this end, we examined how irrelevant auditory similarities across words, that provide no cues regarding their visual or conceptual attributes, influence pseudo-word learning in a name/picture matching paradigm. Two types of irrelevant auditory similarities were used: shared sequences of vowels or consonants. Learning word-to-picture associations in these two conditions was compared to a baseline condition in which items did not share either sequence. Kindergarten children readily learned items in all conditions, but auditory similarity interfered with learning (odds ratio, 1.12). Individual differences in reasoning and vocabulary did not account for the interference effect. These findings suggest that the sensory properties of words continue to influence language learning during the preschool years through rapid incidental learning, even if the effect is relatively small. Consistent with previous studies in the visual modality, we now suggest that incidental perceptual learning occurs in the auditory modality. Furthermore, the current findings suggest that this learning can interfere with word learning, highlighting the importance of the perceptual structure of words in real-world-like learning environments.

Introduction

Learning new words by forming associations between sound sequences and visual referents (e.g., object, people, pictures) is a multifaceted, lifelong process. Multiple studies have documented the roles of different types of linguistic (e.g., phonological, morphological) factors (Gibson, 1971; Hoover, Storkel, & Hogan, 2010; Larsen & Nippold, 2007; McQueen, 1998; Newport & Aslin, 2004; Storkel, 2001; Swingley & Aslin, 2007; Wysocki & Jenkins, 1987) and conceptual factors (see Bloom, 2001 for review) in word learning. On the other hand, the role of perceptual mechanisms and especially perceptual learning, defined as experience-dependent changes in the ability to extract information from the environment (Green, Banai, Lu, & Bevalier, 2018; Samuel & Kraljic, 2009), remains largely unexplored in word learning beyond infancy, even though this learning is active throughout life (e.g., Bradlow, Pisoni, Akahane-Yamada, & Tohkura, 1997; Clayards, Tanenhaus, Aslin, & Jacobs, 2008; Lim & Holt, 2011). The current study aimed to determine whether incidental and rapid auditory perceptual learning influences the formation of word-to-picture associations among kindergarten children. We studied the contribution of incidental perceptual learning by comparing learning outcomes across conditions that varied in the acoustic properties shared (i.e., repeated) across the to-be-learned items. The assumption underlying these comparisons was that differences in learning outcomes between conditions can only arise from perceptual learning, because cognitive, conceptual, and linguistic[1] requirements are the same across conditions.

Studies in infants suggest that perceptual learning is used in the initial stages of word learning (Fennell & Werker, 2003; Stager & Werker, 1997; Swingley, 2008). Whether the same is true when older children learn new words is currently unknown, but a growing

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body of literature on statistical learning of artificial languages suggests that across ages, listeners can use the properties of sound sequences to support the segmentation of unfamiliar sequences (see Newport, 2016; Thiessen & Erickson, 2015, for recent reviews). Furthermore, statistical learning is associated with language processing and comprehension (Conway, Bauernschmidt, Huang, & Pisoni, 2010; Kidd & Arciuli, 2016; Misyak & Christiansen, 2012). Nevertheless, spoken inputs may provide additional sensory cues that are not part of the distributional or conditional structures characteristic of statistical learning studies. Therefore, current statistical learning findings cannot confirm whether the sensory properties of auditory words are subject to incidental perceptual learning, even when these properties are not semantically relevant (semantically relevant refers to cases in which a sensory property provides a consistent cue to the meaning of the stimuli) (see Emberson, Lie & Zevin, 2013 for relevant discussion).

Recent studies suggest that incidental perceptual learning may play a role in language processing (Protopapas et al., 2017; Vlahou, Protopapas, & Seitz, 2012). Incidental visual learning was shown to support learning orthographic structure among Greek-speaking primary school children (Protopapas et al., 2017). Protopapas et al. (2017) presented written words using a dual-task paradigm in which participants performed a color detection task (respond to stimuli of the target color and ignore stimuli of the nontarget color) and a picture recognition task. Words were presented incidentally (participants did not have to attend to the words), paired with either the target or the nontarget color. During a subsequent test, words that previously were paired with the target color during the dual-task phase were recognized more accurately than were words paired with the nontarget color. Furthermore, recognition of new words that shared orthographic structure with the target words was also more accurate than the recognition of new words that did not share the same structure. Pertinent to the current study, Protopapas et al. (2017) suggested that the nonrelevant perceptual attributes of the stimulus array contribute to word-related learning beyond infancy.

The perceptual property of interest in the present study is the information accumulated through the short-term repetition of features that are part of the inherent structure of words in a learning scenario of novel pseudo-words. The current study focused on the presence of across-word perceptual structures that arise through the repetition of nonadjacent regularities. Within each word, nonadjacent regularity refers to a sequence of structurally related elements that occur with other intervening elements in the auditory input. For example, in the Hebrew words ***gadál*** "grew" and ***gadól*** "big," the consonants g-d-l create a nonadjacent regularity. Previous studies suggested that humans learn these nonadjacent regularities and can use them for speech segmentation in artificial language experiments (Frost & Monaghan, 2016; Newport & Aslin, 2004). This type of regularity occurs naturally in languages such as Hebrew, a Semitic language with a typical word-formation mechanism of interleaved (nonadjacent) vowel and consonant sequences. Most content words in Hebrew (nouns, verbs, adjectives) are composed of two nonadjacent sequences (typically called roots and patterns[2]; see the collection of papers in Shimron, 2003). These sequences create shared perceivable properties between words, as in the case of ***gadál*** and ***gadól***, which have the same consonant set (g-d-l), as compared with ***gadól*** "big" and ***kaxól*** "blue," two words that share the same vowel set (a-ó).[3] The repetition of a single, nonadjacent regularity (a consonantal sequence or a vocalic sequence) across words, introduces an acoustic (morphophonological) similarity common to the entire word set (Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000; Frost, Forster, & Deutsch, 1997). The words in such sets are more perceptually similar to each other than they are to words in sets that do not include regularities. Therefore, Hebrew-word-like stimuli can be used to determine whether perceptual similarity *across* words influences word learning through incidental learning.

Studies of word learning among English-speaking preschool and kindergarten children suggest that the statistical properties of the language (e.g., phonotactic frequency, neighborhood density) they speak and hear influence word learning (Hoover et al., 2010; Storkel, 2001). For instance, referent learning in children 3 to 6 years of age was faster for common sound sequences in words that sound similar than for rare sound sequences (neighborhood density effect) (Storkel, 2001). Later studies suggested that whereas frequency and density effects are independent among adults (Storkel, Armbruster, & Hogan, 2006), for children the two effects interact such that words with common sound sequences were learned faster if they came from dense neighborhoods and vice versa (Hoover et al., 2010). Similarly, unfamiliar words that are based on the same nonadjacent consonantal or vowel sequences are treated as related even by young children acquiring Hebrew (Berman, 1987; Berman, 1999; Berman, 2003; Berman & Sagi, 1981; Clark & Berman, 1984; Ravid & Bar-On, 2005; Ravid & Malenky, 2001). Moreover, Hebrew speakers of different ages judge words to be familiar on the basis of their similarity with existing sequences of nonadjacent consonants and vowels, even when the words themselves are unknown (as in the case of the word ***gdil*** "tassel," a rare word also derived from the root g-d-l) (Seroussi, 2011). Taken together, these findings reflect the implicit contribution (Bentin & Feldman, 1990; Bick, Frost, & Goelman, 2010; Deutsch, Frost, Pollatsek, & Rayner, 2005) of previously acquired knowledge to word processing and new word learning. However, after a word has become familiar, its perceptual and conceptual properties are bound together (Hebrew speakers know that words sharing the sequence g-d-l sound similar and convey some meaning related to the notion of size). Therefore, these studies cannot attest to the role of new perceptual information (nonadjacent regularity) in learning, which is the focus of the current study.

To our knowledge, the role of nonadjacent perceptual regularities in word learning among preschool and kindergarten has not yet been directly investigated, but there is evidence that such regularities contribute to speech perception (i.e., syllable identification) among Hebrew-speaking children (Banai & Yifat, 2016). In the current study, children heard lists of familiar words and had to respond to target words that included a specific syllable (e.g., [se]). Recognition of the target syllable was more accurate when target words (e.g., ***séfer*** "book"; ***sélek*** "beet") were mixed with nontarget words that had the same nonadjacent vowel sequence (e.g., ***yéled*** "child", ***kélev*** "dog"), than when mixed with nontarget words with a different vowel sequence (e.g., ***xalóm*** "dream," ***arón*** "closet"). Furthermore, in this age group, greater sensitivity to these regularities was associated with indices of lexical development (Banai & Yifat, 2016; Moav-Scheff, Yifat, & Banai, 2015). Among Hebrew speaking adults, nonadjacent regularities in the form of familiar Hebrew vowel patterns, were found to support auditory word learning in an explicit learning paradigm (Kimel & Ahissar, 2019). In that study, more novel words were learned when the new meanings were embedded within familiar, rather than within novel vowel patterns, but the use of existing Hebrew patterns for the familiar condition made it difficult to determine whether the effect was perceptual or morphological (based on the previous knowledge of adult Hebrew speakers). Therefore, the present study focused on kindergarten children and used nonwords with vowel sets that are uncommon or do not exist in Modern Hebrew, to avoid confounding immediate perceptual learning and long-term linguistic knowledge.

The assumption underlying the present study was that words that share the same nonadjacent sequences (either consonants or vowels) are perceptually similar. As a Semitic language, such words in Hebrew are also conceptually similar, because the sensory regularities carry some level of shared semantic information. This, in turn, means that there is an inherent confounding of the two potential influences on word learning. Nevertheless, perceptual and conceptual information can be artificially dissociated by using pseudo-words that share a consonant sequence or a vowel sequence if they do not convey any shared conceptual information. This requires constructing words based on nonexistent, but possible consonantal and vocalic sequences, and on assigning a unique and arbitrary meaning to each combination.

In a previous study (Moav-Scheff et al., 2015), we constructed new word-like stimuli based on the previously mentioned principles. Preschool children, with either typical language development or with developmental language impairment were taught the names of alien cartoon characters while playing a game during which they were asked to help the aliens perform a variety of daily activities (e.g., play in the park). Children were able to learn to match pictures with the novel names of the different characters, as measured in a recognition test conducted after the learning phase, despite poorer learning in the language impaired group. Therefore, in the present study we reused this paradigm, but manipulated the perceptual similarity across different names between various learning conditions.

The current study

Our goal was to determine whether perceptual regularities created by the repetition of either nonadjacent vowel or consonant sequences across a set of to-be-learned pseudo-words influence word learning and specifically, the formation of picture-referent associations. Unlike previous studies in which perceptual similarities (e.g., a common affix) conveyed class or category information (Ferman & Karni, 2014; Merkx, Rastle, & Davis, 2011; Tamminen, Davis, Merkx, & Rastle, 2012), but similar to the role of color in Protopapas et al. (2017), similarity was not related to the identity of the individual referents.

These pseudo-words were arbitrarily paired with pictures of alien cartoon characters in one of three conditions. A *baseline* condition in which there was no repetition of nonadjacent dependencies across items, and two *repetition* conditions with nonadjacent regularities (introduced through either a *repeated-consonant sequence* or a *repeated-vowel sequence*). The repeated sequences provided no conceptual information (either new or preexisting) about the aliens because of this arbitrary pairing and the use of pseudo-sequences (i.e., that do not exist in Hebrew). Therefore, any difference between the *baseline* condition and either of the *repetition* conditions is necessarily of perceptual origin. Note, that while the use of alien cartoon characters adds a semantic context to the task, it is the same across conditions. Furthermore, children had to learn the names of individual aliens. Therefore, the repeated consonants or repeated vowels did not provide any relevant semantic information about the identity of the aliens. They did not provide any information about class or category membership, either.

Differences between the effects of the two types of regularities (vowels vs. consonants) are indicative of differential sensitivities to different perceptual regularities. Based on the literature reviewed previously, as well as on studies showing that children in this age group are more attuned to perceptual similarities than adults are (Badger & Shapiro, 2012; Sloutsky, Kloos, & Fisher, 2007; Smith, Jones, & Landau, 1996), we hypothesized that the presence of a repeated regularity in either condition should modify performance relative to the baseline condition. However, the direction of the effect (facilitation or disruption) is hard to predict. Whereas adaptation to the repeated sequence might make the nonrepeated elements more salient and thus facilitate learning, the irrelevant similarity induced by that repetition might mask the differences between different names, and interfere with learning. As for differences between consonant and vowel repetitions, although consonants influence lexical access to a greater extent than vowels do (Bonatti, Pena, Nespor & Mehler, 2005; Delle Luche et al., 2014; Nespor, Peña, & Mehler, 2003), others suggested that by the age of 5, consonants may lose their privileged status in new word learning (Havy, Bertoncini, & Nazzi, 2011). In this case, the effects of repeating consonants and vowels in the current study may be similar. Alternatively, a greater effect (either positive or negative) might be expected in the vowel condition because of the greater acoustic prominence of vowels, as compared with consonants (e.g., Jusczyk & Luce, 2002).

Method

Participants

Seventy-nine Hebrew-speaking children (42 girls) participated in this study. Mean age was 5 years 1 month (standard deviation [SD] = 7 months; age range, 3 years, 11 months to 6 years, 6 months). Based on parental reports, all children were typically developing and Hebrew was their only or dominant language. Participants were recruited from kindergartens and afterschool programs in three communities in northern Israel. They were included in the study if their parents confirmed that the child was not diagnosed with or suspected of having any developmental language learning or cognition disorder.

Written informed consent from the parents and verbal assent from the children were obtained before the onset of testing. This study was conducted in accordance with the Declaration of Helsinki and was approved by the University of Haifa ethics committee (196/10). Recruitment and testing in kindergartens were carried out with permission of the Chief Scientist of the Israeli Ministry of Education.

Each participant completed two of the three experimental conditions described in the following section (*baseline* and *repeated-consonant-sequence*, n = 30, or *baseline* and *repeated-vowel-sequence*, n = 49), as well as a short battery of cognitive and language assessments. Some of the data of the group that completed the *vowel-sequence* condition were reported previously in a paper that compared learning on the *baseline* condition between children with typical and atypical language development (Moav-Scheff et al., 2015). To avoid having to choose a subgroup of the typical participants from this current study, we decided to report the data from all participants who completed both learning conditions, resulting in a larger sample in this group. All other data were collected for the purpose of this study and have not been reported elsewhere.

Procedure

Children were tested individually in a quiet room in their kindergarten class or in their own home by one of three female speech and language therapists (including authors R.M.S. and N.B.Z.). A brief battery of language and cognitive assessments and the experimental tasks described next were administered to each participant in two sessions. Each session lasted approximately 30 to 40 minutes (including break periods). One condition of each of the experimental tasks and half of the other tests (see below) were administered at each session. The order of the different tasks was balanced across participants.

Cognitive and language assessments

Cognitive and language assessments were conducted to gain knowledge regarding the performance of the sample on standardized tasks and in relation to learning outcomes. Because the inclusion criteria were based on parental reports and (“mainstream”) school placements, these scores did not serve as grounds for data exclusion even if they fell somewhat below the normal range.

Nonverbal reasoning

Nonverbal reasoning was evaluated using the Block Design subtest of the Wechsler Preschool and Primary Scale of Intelligence (Wechsler, 1989). Scores of 7 or higher on this task are considered normal, and all children but one scored at least 7. One child had a score of 6. Excluding her data had no effect on the outcomes; therefore, the data were retained for analyses.

Grammar

Grammar skills were assessed using the Grammar section of the Katzenberger Hebrew Language Assessment for Preschool Children (Katzenberger, 2009; Katzenberger & Meilijson, 2014), designed to evaluate language skills of Hebrew-speaking children. Scoring and conversion of raw scores to standard scores were completed according to the test manual. Scores in this test are expressed as Z-scores. In our sample, the mean Z-score was 0.42 (SD = 1.1), generally consistent with the population data reported in the test manual.

Vocabulary

Vocabulary was assessed using the Tavor Expressive Vocabulary Test (Tavor, 2011). The Tavor is a standardized picture-naming test for Hebrew speaking children ages 2 to 8 years. Testing was discontinued after five inaccurate or unacceptable answers. Raw scores were converted to Z-scores, as described in the test manual. The mean Z-score in our sample was 0.47 (SD = 0.8), consistent with the population norms.

Experimental stimuli and tasks

Word learning

Incidental word learning was elicited by exposing children to the names and pictures of alien cartoon characters embedded in an interactive game and asking them to help the aliens perform routine daily tasks (e.g., sliding in a playground, crossing a road). Learning was subsequently tested using a recognition task (see the following section). Three word-learning conditions were used: a *baseline* (no repetition) condition and two perceptual repetition conditions (*repeated-consonant sequences* and *repeated-vowel sequences*). In each condition, children were presented with the names and pictures of different aliens. Each participant was tested on two conditions (administered in two separate test sessions), the *baseline* condition and one of the repetition conditions described later. The order of the conditions was balanced across participants.

Stimuli

Each condition included six picture/name pairs. Pictures were of alien cartoon characters, available on the Scratch website (http://scratch.mit.edu/scratch_1.4) at the time of the study. Proper names were used because these typically indicate specific entities (Bloom, 2000). Thus, there was no conceptual similarity between different entities when they were referred to by their names, even when the same name was used for two different people. Although names that share a consonantal or vocalic sequence are more acoustically similar to each other than are names that share neither sequence, this acoustic similarity does not provide any additional semantics when learning to associate the name and picture of the characters. Consequently, only perceptual similarity (i.e., perceptual learning) is expected to have an impact on learning.[4]

Names were two to three syllable pseudo-words that conform to the structure of Semitic languages. As noted, neither of the consonant or vowel sequences selected for this study are in use in Modern Hebrew, but all are permissible based on the phonetic and phonological properties of Hebrew. In the *baseline* condition, the six names differed from each other in both consonants and vowels (e.g., *mularus, duranat*). The names in the repetition conditions either shared a sequence of consonants in the *consonant-sequence* condition (e.g., ***m**u**l**a**m**us* and ***l**u**m**sat* share the consonant sequence l.m.s, interleaved with different vowels) or a sequence of vowels in the *vowel-sequence* condition (e.g., *m**u**l**a**r**u**s* and *m**u**s**a**n**u**d* share the vowel sequence u.a.u).

Exposure stage

Participants played a 5-minute long interactive game (administered using Microsoft Office PowerPoint software). The purpose of the game was to elicit the learning of new picture/pseudo-word associations by presenting the names and pictures of the alien characters while engaging the children in an interactive age-appropriate activity. The exposure stage had three phases during which each name was repeated a total of nine times. Before the first phase, children were prompted with "let's play this new game." In the first phase, the name of each alien was repeated three times, embedded in short phrases such as "Here is mularus. Hello mularus. See you later mularus." In the second phase, all six aliens and their names appeared again, individually. At this point, the child was asked to click the picture of the alien using the "magic wand" on the screen to make it do something. For example, children were told "mularus likes going to the playground. Mularus likes the slide best of all. Can you help mularus with your magic wand?" During this phase, each name was presented three times. In the third and last phase of the game, the names of the aliens were again presented three times each, embedded in a goodbye scenario ("Goodbye mularus, see you later mularus, it was nice meeting you mularus.").

Test stage

After playing the game, the familiarity of the name/picture associations was tested with a multiple-choice recognition test. For each trial, three pictures and a name were presented and children had to point at the alien whose name was presented (e.g., "where is mularus, can you please show me mularus?"). The pictures were presented simultaneously on a computer screen and remained on screen until the child responded. The name was presented by the experimenter who then waited for the child to respond. One picture was that of the target alien, whereas the other two were distractors. One of the two distracters was the picture of another alien from exposure stage. The other distracter was a picture of an entirely new alien. The name of each of the six aliens was repeated three times for a total of 18 trials. The total number of correct responses was counted, along with the number of type 1 errors (choosing the distracter that appeared in the exposure phase) and type 2 errors (choosing the new distracter). However, across children and conditions, > 91% of errors were type 1; therefore, only the number of correct responses was used for statistical analysis. Scores greater than six reflect better than chance performance, and were taken as an indication that learning occurred during the condition in which the score was observed.

Phonological memory

A phonological memory task modeled after standard span tasks used in assessments of working memory (e.g., Digit Span) was used. This task was developed by Oganian and Ahissar (2012) and adapted for use in preschool children in a previous study in our lab (Banai & Yifat, 2012). In this task, syllables were read by the examiner in a rate of one per second under two conditions ("no repetition" and "with repetition"). Children were asked to listen carefully and repeat each list exactly as they heard it. Syllables were ordered as to not produce any meaningful bi- or poly-syllabic Hebrew words (e.g., /ve/,/ba/,/zi/). The first list was two items long and the length increased up to a maximum of nine items per list. Two lists were presented for each list length. Testing stopped after failure to correctly repeat two lists of the same length. Only items in which all the syllables were repeated in the order of presentation were counted as correct responses and received one point. Final scores could thus range from zero to 16. In the "no-repetition" condition, different syllables were presented in each list (e.g., na-bi; ma-še-do). The "with-repetition" condition was designed to induce context by repeating, in each new list, the syllables from a shorter list with the addition of a single new syllable (e.g., ve-ba ; ve-ba-zi). A pair of lists of the same length included completely different syllables. Thus, a context effect could have occurred only across lists of different lengths.

This task is known to yield strong positive context effects in children (Banai & Yifat, 2012; Banai & Yifat, 2016) and in adults (Oganian & Ahissar, 2012) and was included in this study only as a control condition. Had our experimental task yielded no repetition effects, data from this task would have been used to determine the presence or absence of context effects in the current sample of children. Because this was not the case and because some of the data for this task were presented

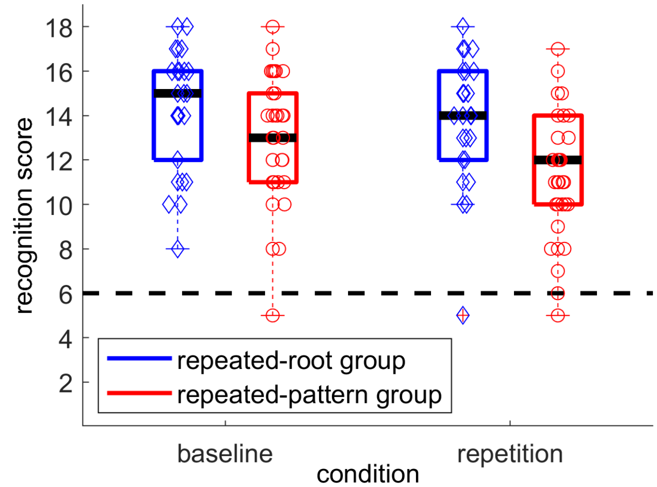

Figure 1. Name-picture matching (recognition scores) by group and condition. Left two boxes: Scores on the *baseline* condition. Right two boxes: Scores of the two groups on the *perceptual repetition* condition in which one element (consonant or vowel sequence) was repeated across items. Diamonds/circles denote data of individual participants in the repeated-consonants and repeated-vowels groups, respectively. Box edges mark the interquartile range, the thick line within each box marks the median, and the whiskers are 1.5 times the interquartile range. The dashed line marks chance level. For means and standard deviations, see text.

and discussed elsewhere (Moav-Scheff et al., 2015), the outcomes are reported briefly only.

Results

Children in the *repeated-consonants* and *repeated-vowels* groups were of similar age and nonverbal reasoning ability, but scores on the language assessments were somewhat higher in the *repeated-consonants* group (Table 1). Independent sample *t*-tests suggested that the only significant difference was in vocabulary (Table 1, rightmost column). The putative influence of this difference on the perceptual context effect was taken into account by including language and reasoning scores in the analysis of the context effects (in the final section of the Results).

Performance on the experimental tasks

The vast majority of participants, performed well above chance on the recognition tests of all three experimental conditions (*baseline*, repeated-*consonant-sequence* [consonant], repeated-*vowel-sequence* [vowel]) (Figure 1). This suggests that overall, our paradigm was effective in eliciting learning of the name/picture

	Repeated-consonants group	Repeated-vowels group	*t*
Age (months)	61 ± 9 [49–77]	62 ± 7 [47–78]	−0.28*
Block design (scaled score)	13 ± 3 [9–18]	14 ± 3 [6–19]	−1.59*
Grammar (standard score)	0.62 ± 1.0 [−1.2–2.8]	0.30 ± 1.2 [−2.5–3.1]	1.21*
Vocabulary (standard score)	0.78 ± 0.7 [−0.49– 3.23]	0.28 ± 0.8 [−2.37–1.48]	2.66†

Table 1. Descriptive statistics (mean ± standard deviation [range]) by group. *Notes*: * $p > 0.05$; † $p < 0.01$.

associations. Scores were somewhat higher in the *baseline* condition (consonant group: 14.37 ± 2.7; vowel group: 12.90 ± 2.6) than in the *perceptual repetition* conditions (consonant group: 13.80 ± 2.7; vowel group: 11.49 ± 2.6). Scores were also somewhat higher in the consonant group than in the vowel group. Because recognition scores (the dependent variable) were measured as counts, a Poisson regression was used to determine whether group differences and perceptual learning effects were statistically significant.

Effects of perceptual repetition on the performance of the experimental tasks

A Poisson regression with log of the recognition score as a dependent variable and group (repeated-consonants, repeated-vowels), experimental condition (baseline, repetition) and order (baseline first, repetition first) as explanatory variables was conducted using the GLMMIX procedure in SAS. A mixed model was used because recognition scores were correlated between the baseline and the repetition conditions. As suggested by Figure 1, a significant main effect of group was found ($\beta = 0.1859 \pm 0.049$, $t(76.65) = 3.81$, $p = 0.0003$, odds ratio = 1.20), indicating that children in the repeated-consonants group learned more name/picture associations than children in the repeated-vowels group did. A significant *negative* effect of repetition was also found ($\beta = 0.1166 \pm 0.035$, $t(76.79) = 3.34$, $p = 0.0013$, odds ratio = 1.12), which suggests that the repetition of either consonant or vowel sequences impeded the learning of name/picture associations with this paradigm (Figure 2). The effect of order ($\beta = 0.0381 \pm 0.039$, $t(75.71) = 0.99$, $p = 0.33$) and the interaction of group and context ($\beta = -0.0764 \pm 0.054$, $F(76.37) = 1.42$, $p = 0.16$) were not significant.

Figure 2 shows the repetition effect of individual participants and at the group level. This effect was calculated as the ratio between the baseline

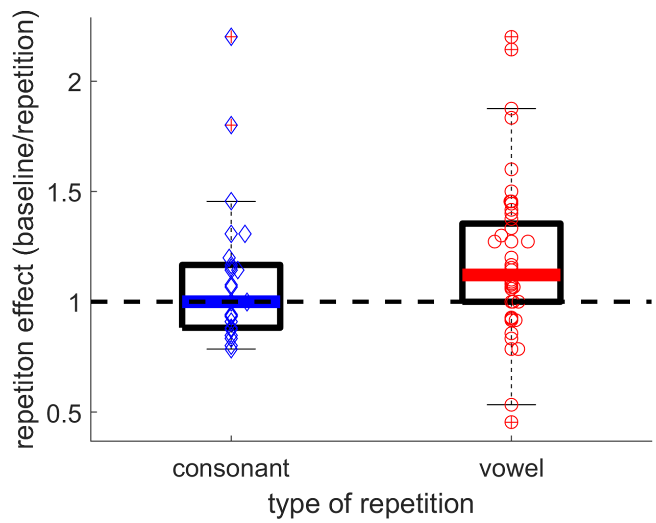

Figure 2. Effects of repeating consonants (left) and vowels (right). Values larger than 1 (above the dashed line) suggest that performance in the *baseline* condition was more accurate than performance in the *context* condition and therefore are taken as evidence that perceptual repetition interferes with learning. Diamonds/circles denote data of individual participants in the repeated-consonants and repeated-vowels groups, respectively. +Denotes outliers. Box edges mark the interquartile range, the thick line within each box marks the median, and the whiskers are 1.5 times the interquartile range.

and the perceptual repetition condition for each participant. Therefore, values greater than 1 indicate that performance in the repetition condition was poorer than in the baseline condition. Despite the lack of a significant group-by-repetition interaction, the across-word repetition of a vowel sequence may have interfered with learning to a greater extent than the repetition of a consonant sequence did (Figure 2). To further explore this option, a simple effect comparison between the *baseline* and the *repetition* conditions was carried out for each of the groups, separately. These comparisons yielded a significant vowel-induced effect ($\beta = 0.0841 \pm 0.032$, $t(76.37) = 2.94$, $p = 0.0047$, equivalent to a ratio of 1.09 in favor of the *baseline* condition), but an insignificant consonant-induced effect ($\beta = 0.0402 \pm 0.041$, $t(76.04) = 0.98$, $p = 0.3307$ equivalent to a ratio of 1.04 in favor of the *baseline* condition). However, this small difference between the groups was probably too small to result in a significant interaction in our main analyses. Therefore, we suggest that the current findings are consistent with the idea that repetition of a structure within a word interfered with learning, especially when induced by repeating a vowel sequence.

Alternatively, it could be argued that the repeated-consonants group was not sensitive to repetitions and therefore did not show an effect for repeating consonants. However, we do not believe this to be the case because in the phonological memory task, the mean repetition effect in the *repeated-consonants* group was 2.3 items (SD = 2.3) compared with a mean effect of 1 item (SD = 1.7) in the *repeated-vowels* group (Mann-Whitney test: $Z = 2.69$, $p = 0.007$). In fact, the stronger effect of repetition on phonological memory in the repeated-consonants group could be expected based on previous studies showing that larger repetition effects in this task are associated with better language skills (Banai & Yifat, 2012; Banai & Yifat, 2016) and better word learning overall (Moav-Scheff et al., 2015).

Were perceptual learning effects influenced by language and reasoning skills?

Across all participants, the magnitude of the repetition effect was not correlated with performance on either of the language (grammar: $r = 0.13$, $p = 0.26$, vocabulary: $r = 0.025$, $p = 0.83$) or reasoning (block design: $r = 0.044$, $p = 0.706$) background tasks. It therefore seems unlikely that the significant repetition effect we observed was the sole outcome of individual differences in either of these measures. Nevertheless, because significant differences in vocabulary were observed between the two groups of participants who completed the *vowel-repetition* and the *consonant-repetition* conditions, vocabulary was added to the regression model to determine whether it could account for the finding that a significant context effect was induced by a vowel-sequence context but not by a consonant-sequence context. The effect of vocabulary was marginally significant ($\beta = 0.0404 \pm 0.026$, $t(71.04) = 1.96$, $p = 0.054$), suggesting it may have had a small effect on the overall learning in this paradigm. Nevertheless, the repetition effect remained significant for the repeated vowels sequence ($\beta = 0.1394 \pm 0.036$, $t(73) = 3.86$, $p = 0.0002$ with an odds ratio of 1.15 in favor of the *baseline* condition) and not significant for the repeated consonant sequence ($\beta = 0.0402 \pm 0.041$, $t(73) = 0.98$, $p = 0.329$).

Discussion

As noted at the beginning of the paper, the current study aimed to test the hypothesis that incidental perceptual learning, elicited by perceptual similarities (in either vowels or consonants) across words influenced the formation of novel associations between names and pictures. We achieved this by separating perceptual similarity from cognitive abilities and conceptual similarity, which are also involved in word learning. The major goal of the study was borne out: consistent with our hypothesis, incidental perceptual learning elicited by acoustic similarity across words was shown to have a significant impact on word-learning in children around the age of 5. Although speech perception is still not mature at this age (Hazan & Barrett, 2000; Hoonhorst et al., 2011), children are nevertheless processing and learning perceptual regularities across words. Furthermore, this processing seems automatic or obligatory because in the present study, acoustic regularities did not afford any categorical or semantic information, and children were not informed or otherwise cued of their presence.

Although the current data cannot speak to developmental trends in perceptual learning, we note that within the age range of our sample (31 months), age was not correlated with the perceptual repetition effect. Specifically, significantly *weaker* learning was observed in the presence of perceptual similarity (Figure 1). A follow-up analysis suggested that repetition of a single vocalic sequence may be more disruptive than the repetition of a single consonantal sequence (Figure 2). However, because the difference between consonants and vowels only emerged in a follow-up analysis in which each type of repetition was compared with the baseline, we consider it tentative and suggest that further work is needed to directly compare consonant and vowel sequences. The repetition effect was not related to overall differences in reasoning or language skills, as assessed in this study. We argue that the findings are consistent with the idea that incidental perceptual learning of the sensory structure of words influences referent learning, even when this structure carries no useful information. As discussed next, whether the effect of perceptual learning is facilitative or disruptive may depend on the nature of the learned structure and on whether it provides task-relevant information.

An important facet of this study is that the methodology was designed to isolate perceptual effects on learning by decoupling sensory structure from the meaning of the pseudo-words used. Earlier studies are inconsistent with respect to the influence of repeated sensory features on auditory perception and on auditory perceptual learning. Repetition of sensory information across stimuli was found to support the perception (i.e., recognition or discrimination) of nonverbal auditory stimuli (Banai & Yifat, 2011; Nahum, Daikhin, Lubin, Cohen, & Ahissar, 2010), speech stimuli (Bent, Frush & Holt, 2013; Inoue, Higashibara, Okazaki, & Maekawa, 2011; Martin, Mullenix, Pisoni & Summers, 1989), and discrimination learning (Cohen, Daikhin, & Ahissar, 2013). However, hearing a variety of speakers benefits the learning of new phonetic categories (Bradlow et al., 1997; Lively, Logan & Pisoni, 1993) and learning to recognize accented speech (Bradlow & Bent, 2008; Brosseau-Lapre, Rvachew, Clayards & Dickson, 2013; Clopper & Pisoni, 2004; Sidaras, Alexander & Nygaard, 2009). Evidence from statistical learning studies also suggest that the perceptual organization of the input interacts with learning. For example, when learning new auditory categories, the ability to learn the new categories was found to depend on the low-level properties of the exemplars populating each category, even though these attributes were not relevant to the definition of the category itself (Emberson, Liu & Zevin, 2013). Likewise, among first-grade children learning to read, learning new grapheme-to-phoneme correspondences for vowels was found to depend on the irrelevant perceptual characteristics of the wordlists used in training (Apfelbaum, Hazeltine & McMurray, 2013). Children were presented with lists in which the words were either more (e.g., bat, hat, pat, cat), or less (e.g., fan, pat, pal, ram) similar with respect to consonants shared across words. Generalization of the vowel to new words was better in the less similar condition. That is, consistent with the current findings, limiting the amount of irrelevant sensory repetition across stimuli can also be detrimental in other instances of perceptual and statistical learning. For a more specific discussion in the context of word learning, see the next section.

In the current study, we focused on kindergarten children, a population that does not receive much attention in current research on perception. In our case, these children were native speakers of a unique type of language – Hebrew, a Semitic language in which nonadjacent sequences are an inherent feature that typically confounds perceptual and conceptual information, but that also allows for experimental differentiation between the two. Therefore, generalizing the current findings to non-Semitic languages requires further studies in which meaningless similarities are introduced through structures that are common in those languages (e.g., made-up affixes in languages with linear morphology, such as English). Nevertheless, the findings that the perceptual features of to-be-learned items, such as characteristics of the speaker (e.g., Bradlow & Bent, 2008) and even the structure of nonverbal categories (Emberson, Liu & Zevin, 2013) influence learning, suggest that the effects of perceptual similarity observed here are probably not specific to Hebrew.

Another issue associated with studying kindergarten children is that, by this age, children have already started to acquire literacy. As the age range of our sample was quite broad, it is likely that the children had different levels of literacy, which we could not have accounted for in our group comparisons. As literacy development contributes to the development of oral language skills (e.g., Cunningham & Stanovich, 1991; Morais, Bertelson, Cary & Alegria, 1986), this suggests that the higher vocabulary scores observed in the repeated-consonants group in the current study could reflect more advanced literacy in some of the children in this group. Although the repetition effect in this study was not related to oral language skills, and therefore not likely affected by this confound, this is a limitation of the study.

Perceptual learning may interfere with word learning

In word learning, previously acquired knowledge about the phonological structure of language facilitates word learning in children (Hoover et al., 2010; Storkel, 2001). These studies focused on long-term representations that are related to phonological families created on the basis of the frequency of adjacent sequences in the language to which children are exposed on a daily basis. On the other hand, we reported that the online introduction of a novel perceptual regularity, based on the frequency of nonadjacent sequences in short-term input, disrupted learning. Two reasons could have contributed to this discrepancy.

First, it has been repeatedly and consistently shown that phonologically similar words are harder to recall than phonologically dissimilar words (Baddeley, 1986; Gathercole & Baddeley, 1990; Montgomery, 1995). In adults, phonological similarity facilitated online learning, but interfered with the memory of the learned words over time (Storkel, Bontempo, & Pak, 2014). In the current study, testing occurred immediately after exposure; thus, we cannot separate weaker learning from faster decay of phonologically similar items. Because we tested children, it could be that memory decay was faster in the current study than in that of Storkel et al. (2014).

A second reason why perceptual similarity was facilitative in past studies but disruptive here could be that the role of similarity could change as a function of its task relevance. We suggest that to support word learning, similarity has to be informative, similar to what has been demonstrated for visual category learning in children (Sloutsky et al., 2007). Findings from previous studies of word learning are consistent with this idea. First, arbitrary pairings of sound and meaning were found to interfere with word learning in adults (Nygaard, Cook, & Namy, 2009). In this study, monolingual, native English speakers were introduced to Japanese words in three different conditions. In one condition, each Japanese word was presented with its matching English translation; in another condition, each Japanese word was presented with its English antonym, and in a final condition each Japanese word was randomly paired with an English antonym of another word from the learning set. When tested, participants were slower to recognize words from the random condition. Another example comes from cross-situational word learning (Kachergis, Yu, & Shiffrin, 2016; Ramscar, Dye, & Klein, 2013), in which participants are exposed to an array of several novel objects and their pseudo-word labels in each trial. Participants have to learn the correct label for each object even though the correct pairings are never indicated. It was shown that in such situations, pairings that appeared in the context of only few other pairings (low contextual diversity) were harder to learn than pairings that appeared in the context of more pairings (greater contextual diversity), over time. This is presumably because greater contextual diversity provides more information about specific pairings and thus, strengthens the associations between words and the objects they represent (Kachergis et al., 2016). Similarly, in an ambiguous word-learning study, children learned the object/label pairings based on how informative the label was with respect to an object (Ramscar et al., 2013). Thus, if ambiguous label X was presented with objects A and B, and ambiguous label Y was presented with objects B and C, children learned that X was the label corresponding to object A. If this interpretation is correct, perceptual similarity in the current study would have facilitated learning if it was somehow relevant to the identity of the aliens; for example, if similar-sounding alien names indicated aliens that also shared visual features.

Facilitative effects of similarity were previously found in neural (Chandrasekaran, Hornickel, Skoe, Nicol, & Kraus, 2009) and in behavioral (Banai & Yifat, 2012; Chandrasekaran et al., 2009; Inoue et al., 2011) studies. In these studies, similarity was created through syllable repetition. In another study (Banai & Yifat, 2016, see Introduction), syllable identification was assessed by asking children to respond to words that started with a target syllable. Similar to the present study, perceptual context was created by the repetition of nonadjacent vowel sequences. The regularities that were facilitative in the previous studies but disruptive here, are assumed to be automatically and implicitly processed. This automatic processing allows the incorporation of previously encountered information with ongoing stimulus processing (e.g., Tenenbaum, Kemp, Griffiths, & Goodman, 2011). Since performance is based on the integration of current and previous information, repetition of a single sequence across words is expected (according to Bayesian accounts) to result in greater agreement between prior and current information and therefore in enhanced identification (Xu & Tenenbaum, 2007). In the current study, however, the ability to accurately associate the names of the aliens with the correct pictures critically depended on the ability to differentiate the words. Therefore, an automatic process of integration across names might have resulted in confusion between aliens with similarly sounding names. We thus suggest, that in order to facilitate performance, similarity has to provide task-relevant stimulus statistics or prior information.

Finally, we consider the negative context effect observed in this study in light of what is known about word structure in a language such as Hebrew. Overall, our results suggest that in word learning, kindergarten children rely on identifying phonological structures and nonadjacent regularities among speech sounds, as well as the element type that is regularly related (see Newport & Aslin, 2004). In our study, we relied on what is discussed in the literature as the underlying morphophonological properties of Hebrew words (Arad, 2006; Berman, 1987; Berman, 2003; Clark & Berman, 1984; Ravid et al., 2016; Segal, Nir-Sagiv, Kishon-Rabin, & Ravid, 2009; Shimron, 2003). Whereas in earlier studies of word learning, phonological similarities were tied to the perceptual attributes of a given semantic category or based on affixes that conveyed class information (Ferman & Karni, 2014; Merkx et al., 2011; Tamminen et al., 2012), this was not the case here. By dissociating this morphophonological structure from the semantics typically associated with it when using existing words, we were able to ask whether the perceptual repetition of this structure influences learning. Further studies are required to determine whether such repetition is sufficient to influence word learning, as well as learning new semantic or linguistic categories that share the repeated structure.

Keywords: incidental learning, anchoring, nonadjacent dependencies

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Footnotes

[1] With the exception of possible differences between consonants and vowels, which are discussed where relevant.
[2] In the current study, we purposefully avoid the terms *root* and *pattern* because these are defined based on phonological structure as well as on their inherent semantic information. Here, no morphological meaning is assigned to either consonant or vowel sequences to allow for the exploration of the role of perception in the process of word learning.
[3] Thus, the root g-d-l (which refers to the concept of size) yields various words such as *gdila* "growing," *migdal* "tower, large building," *gadlut* "greatness," and *hagdala* "enlargement"; see Berman (2017).
[4] To rule out that potential effects in this study result from sensory similarity influencing perception (e.g., from phonological competition) rather than learning, a pilot study was conducted using a minimal-pair discrimination task. For each trial, two words (either the same or different by a single phoneme) were played and children had to determine whether the words were the same or not. Two conditions were administered (24 trials/condition), one in which words across all pairs shared the same syllable sequence (as in the syllable-repetition condition of the main experiment), and another in which syllable structures differed across words (as in the baseline condition). Thirty-two children in the same age range as the main study completed the pilot. Sensitivity (d') scores were calculated for each condition. Average d' was 2.5 ($SD = 0.8$) on the repeated syllables condition and 2.6 ($SD = 0.9$) without repetition ($t = 0.52$, $p = 0.61$; Cohen's $d = -0.09$; Bayesian analysis: $BF_{10} = 0.21$). Therefore, the pilot data suggest that, at least as tested here, syllable repetition across words did not make the individual words substantially harder to perceive.

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