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Brief article

Statistical learning and spelling: Evidence from an incidental learning experiment with children

Anna Samara*, Daniela Singh, Elizabeth Wonnacott

Division of Psychology and Language Sciences, University College London, United Kingdom

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ABSTRACT

Statistical learning processes–akin to those seen in spoken language acquisition (Saffran et al., 1996)–may be important for the development of literacy, particularly spelling development. One previous study provides direct evidence for this process: Samara and Caravolas (2014) demonstrated that 7-year-olds generalize over permissible letter contexts (graphotactics) in novel word-like stimuli under incidental learning conditions. However, unlike in actual orthography, conditioning contexts in Samara and Caravolas' (2014) stimuli comprised perfectly correlated, redundant cues in both *word-initial* and *word-final* positions. The current study explores whether 7-year-olds can extract such constraints in the absence of redundant cues. Since theories of literacy development predict greater sensitivity to restrictions within word-final units, we also contrast learning in word-initial and word-final units. We demonstrate that–for 7-year-old learners in two linguistic contexts (English and Turkish)–there is substantial evidence for the learning of both types of restriction.

1. Introduction

Many empirical studies with infant and adult learners have established that statistical learning processes operate at multiple levels of spoken language (e.g., phonology, morphology, syntax) acquisition. Written language is another statistically patterned domain of knowledge, yet little work has directly assessed whether the same learning mechanisms are at play during spelling development, and how these are constrained. We report on a learning experiment with English- and Turkish-speaking children that addresses these questions.

Computational analyses of the English orthography has revealed a range of probabilistic rules that constrain the use of different graphemes in particular positions and contexts (Kessler & Treiman, 2001). Importantly, children are sensitive to such constraints. For example, Treiman and Kessler (2006) showed that 11-year-olds, asked to spell nonwords, were more likely to spell /ɛ/ followed by /d/ as "ea" (e.g., /glɛd/→ glead) as opposed to /ɛ/ followed by other codas (/glɛp/→ glep); eight-year-olds were more likely to spell /ɑ/ as "o" when preceded by the onset /w/ (e.g., / kwɑp /→ quap) as opposed to other onsets (e.g., /l/) (e.g., /blɑp /→ blop). These results suggest that children show sensitivity to contingencies between vowel spellings and the adjacent following/preceding consonants, and similar findings are seen in nonword judgments, in children's own spelling errors, and for different type of constraints (e.g., purely graphotactic rules where conditioning has no phonological counterpart) (Cassar & Treiman, 1997; Hayes, Treiman, & Kessler, 2006; Pacton, Perruchet, Fayol, & Cleeremans, 2001; Pacton, Sobaco, Fayol, & Treiman, 2013; Treiman, 1993).

The key premise of these studies is that pattern knowledge develops from text exposure via statistical learning. Samara and Caravolas (2014) directly tested this among 7.5-year-olds building on work by Onishi, Chambers & Fisher (2002) in the phonotactic domain. They assessed learning of graphotactic "rules" that resembled those encountered in written English (e.g., "g and z cannot co-occur") but were novel in nature (e.g., "o and p cannot co-occur"). The incidental learners saw Consonant-Vowel-Consonant letter strings while performing a cover (color detection) task. Unbeknown to them, there were restrictions between consonants and the neighbouring vowel *both* word initially (e.g., medial *o* was always preceded by two out of four consonants such that, for example, strings could not begin with *po*), *and*

* Corresponding author at: Division of Psychology and Language Sciences, University College London, Chandler House, 2 Wakefield Street, London WC1N 1PF, United Kingdom.

E-mail address: anna.samara@ucl.ac.uk (A. Samara).

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word finally (e.g., medial *o* was also followed by only two out of four consonants such that, for example, strings could not end with *ol*). At test, children discriminated "permissible" from "impermissible" novel stimuli suggesting learning and generalization over the novel restrictions without explicit instruction.

Samara and Caravolas (2014) provide strong first evidence that 7-year-olds rapidly extract graphotactic restrictions using similar processes to those at work in spoken language acquisition. This challenges popular models of literacy development, which propose that sensitivity to spelling emerges "late" (Frith, 1985; Marsh, Friedman, Welch, & Desberg, 1980). However, stimuli were designed to maximize cues available to the learner: vowels were cued by both preceding and following context, whereas earlier work (e.g., Treiman & Kessler, 2006) has investigated children's sensitivity to *each* cue in isolation. Disentangling learning from preceding versus following context is particularly important given a long-standing debate regarding the relative importance of word-initial and word-final units in literacy development. One view (Fudge, 1969, 1987; Selkirk, 1982, Treiman, 1986; Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995), is that syllables are represented as a "block" that contains the initial consonant (s), defined as the onset, and a "block" that contains both the vowel and word-final consonant(s), defined as the rime, with rimes being behaviourally relevant for developing literacy performance (e.g., Goswami & Bryant, 1990; Kirtley, Bryant, MacLean, & Bradley, 1989; MacKay, 1972; Treiman, 1983, 1985). For example, it has been shown that reading using rime (word-final-unit) analogies (e.g., *pin* on the basis of *win*) emerges earlier in development relative to reading using body (word-initial-unit) analogies (e.g., *pin* on the basis of *pig*) (Goswami, 1986, 1988, 1991; Goswami & Bryant, 1990). On the other hand, rime advantages do not hold in some other work (Geudens & Sandra, 2003; Geudens, Sandra, & Van den Broeck, 2004; Geudens, Sandra, & Martensen, 2005), and may be task dependent (e.g., Duncan, Seymour, & Hill, 1997; Bowey, Vaughan, & Hansen, 1998; Savage, 2001). We add to this work by comparing children's ability to learn constraints from word-initial and word-final units.

1.1. The current study

We assessed 7-year-olds' ability to learn novel graphotactic restrictions either in word-initial units (i.e., between word-initial consonants (C_1s) and the adjacent following vowel) or in word-final units (i.e., between word-final consonants (C_2s) and the adjacent preceding vowel). English-speaking (Exp.1) and Turkish-speaking (Exp.2) children were tested using adapted orthographic stimuli. This allows us to generalize our findings across children previously exposed to quite different orthographic systems: Turkish has much more regular sound-to-letter correspondences than English (Öney & Durgunoğlu, 1997).

We replicated the methods of Samara and Caravolas (2014), with two modifications. First, given the greater potential difficulty of learning in this experiment (since redundant cues were removed), exposure occurred over two sessions (rather than one). Secondly, instead of a single-letter detection task, which may have attenuated children's ability to learn two-letter restrictions, we asked children to respond to a change in color across the three letters.

We predicted that both English- and Turkish-speaking children would extract the graphotactic regularities exemplified during training both across conditions (hypothesis-1), and in each condition (hypothesis-2), and stronger learning from word-final than word-initial units in both linguistic contexts (hypothesis-3).

2. Methods

2.1. Participants

Seventy-eight Year 2 English-speaking children (mean age = 7.24 years) and 37 monolingual Turkish Grade 1 children (mean age = 6.73 years) were recruited from primary schools in England and Turkey, respectively.[1] Note that our original sample was 40 English-speaking children; an additional 38 participants were recruited in light of some inconclusive Bayes Factor (BF) results.[2] Participants were randomly allocated to the word-initial condition (45 English-speaking children; mean age = 7.14 years; 19 Turkish-speaking children; mean age = 6.71 years) and word-final condition (33 English-speaking children; mean age = 7.37; 18 Turkish-speaking children; mean age = 6.75 years).[3,4] All-but-four participants completed two sessions on two consecutive days.[5]

2.2. Material

Thirty-two C_1VC_2 pronounceable English letter strings (30 nonwords, e.g., *gop*; 2 words) were created using four consonant graphemes as C_1s (*d*, *g*, *l*, *m*), four consonant graphemes as C_2s (*b*, *p*, *r*, *s*), and *o* and *e* as word-medial vowels. All graphemes and the resulting bigrams were both permissible and frequent within English words in their respective positions. Thirty-two pronounceable Turkish nonwords (e.g., *küç*) were similarly created using different letters from the Turkish alphabet to minimize the presence of unnatural letter strings. In each case, stimuli were arranged into four lists, three of which served as exposure, legal unseen and illegal materials for each participant. Item assignment to list was counterbalanced across participants, such that, stimuli that served as legal items for half of the children were illegal items for the other half, and vice versa.

As shown in Fig. 1, for stimuli in the *word-initial condition*, two of the four C_{1s} preceded *o* and the remaining 2 C_{1s} preceded *e* (e.g., in one counterbalanced list, $p(\text{d/g, o}) = p(\text{l/m, e}) = .25$) whereas C_{2s} followed both *o* and *e* with equal probability ($p(\text{o,b}) = p(\text{e,b}) = .125$). That is, C_{1s} were the only predictive cue of the *adjacent following* vowel's identity. For stimuli in the *word-final condition*, two of the four C_{2s} followed *o* and the remaining 2 C_{2s} followed *e* (e.g., in one counterbalanced list, $p(\text{o, b/p}) = p(\text{e, r/s}) = .25$) , whereas C_{1s} preceded both vowels with equal probability ($p(\text{d,o}) = p(\text{d,e}) = .125$). That is, C_{2s} were the only predictive cue of the adjacent preceding vowel's identity.

Eight pattern-conforming stimuli were presented during exposure and another eight served as legal unseen test items. Eight illegal items (presented at test) violated the patterns.

2.3. Procedure

Children were introduced to a toy "froggy" and were invited to play

[1] While we did not systematically conduct standardized tests of literacy ability, we collected reading scores from the WRAT and TOWRE for a subset of our English-speaking participants. These were as follows: WRAT-IV: mean = 118.00, SD = 9.79, n = 18; TOWRE: mean = 118.79, SD = 11.03, n = 57. These standardized results suggest that the children we have recruited were above typical levels, possibly due to the fact that we used an opt-in recruitment procedure (as is typical in many developmental studies): that is, parents of higher achieving children are more likely to give consent for them to participate in research. As a further check, for those children where we had available data, we looked for correlations between their literacy scores and their performance on our experimental task: none were present (WRAT: r = -.15, p = .546; TOWRE: r = .11, p = .419), suggesting our experimental effects were not carried by exceptional readers.

[2] In contrast to the interpretation of p values in frequentist analyses, Bayes Factors remain a valid measure of evidence even with optional stopping (Dienes, 2016; Rouder, 2014).

[3] Of the 78 English-speaking children, 69 were monolingual English speakers. The remaining children were reported to be bilingual but were not literate in their second language.

[4] Due to different policies regarding age of school entry in England and Turkey, Turkish-speaking children were significantly younger relative to their English-speaking counterparts, $t(113) = 5.61$, $p < .001$, $d = 1.02$.

[5] Four Turkish-speaking children completed the sessions over 3 to 6 days.