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What predicts successful literacy acquisition in a second language?

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Abstract

We examined whether success (or failure) in assimilating the structure of a second language could be predicted by general statistical learning abilities that are *non-linguistic* in nature. We employed a visual statistical learning (VSL) task, monitoring our participants' implicit learning of the transitional probabilities of visual shapes. A pretest revealed that performance in the VSL task is not correlated with abilities related to a general G factor or working memory. We found that native speakers of English who picked up the implicit statistical structure embedded in the continuous stream of shapes, on average, better assimilated the Semitic structure of Hebrew words. Our findings thus suggest that languages and their writing systems are characterized by idiosyncratic correlations of form and meaning, and these are picked up in the process of literacy acquisition, as they are picked up in any other type of learning, for the purpose of making sense of the environment.

Most modern societies today include as an integral part of their educational curriculum the learning of a second or foreign language, whether because they are multilingual societies, or simply because globalization emphasizes the need for a Lingua Franca. Beginning with Carroll's seminal work (e.g., Carroll & Sapon, 1959), studies tracking the process of L2 acquisition have suggested that individuals substantially differ in their capacity to learn another language (e.g., Sparks et al., 2009; Lundberg, 2002). Whereas some seem to assimilate a new linguistic system with relative ease, for others this task involves significant difficulty. What determines this variability? What predicts successful and fast acquisition of an additional language?

The question of the source of individual differences is seldom straightforward (see Dewaele, 2009). Many factors can be offered to explain success or failure in any given task, and pinpointing a single mental capacity to account for the population variance in performance is difficult in most cases. For example, research on L2 spoken language and literacy acquisition has suggested that success is moderated by a variety of individual differences in factors such as context of language exposure, phonological abilities, working memory, executive functions, motivation, or personality traits (e.g., Kroll & Linck, 2007; Bialystok et al., 2008; DeKeyser, 2000; Dewaele, 2009). In the present context, however, we were concerned with adjudicating between two qualitatively different theoretical approaches to L2 acquisition in young adults: the first considers it to be a domain-specific capacity belonging to the modular faculty of language, while the second considers it to reflect a *general* and non-linguistic cognitive capacity for statistical learning.

The view that second language acquisition is a subset of the language faculty of cognitive architecture argues that L2 learning is mediated by the same linguistic capacities as L1 learning, and by similar neurocircuitry. Indeed, it has been shown that L1 linguistic capacities such as phonological awareness, syntactic abilities, orthographic knowledge or vocabulary, generally predict success in L2 acquisition (e.g., Ganschow et al., 1998). Similarly, the level of literacy achieved in one's native language has been shown to determine, to a large extent, the acquisition of literacy in a foreign language (e.g., Koda, 2007). Moreover, L2 neurocircuitry has been shown to converge with L1 neurocircuitry as L2 proficiency increases (e.g., Abutalebi et al., 2001). According to this approach, mastering literacy in a second language draws upon specific capacities that are *specific to language*, and therefore linguistic measures are the best predictors of success in this task.

The theoretical approach underlying the claim that second language learning mainly reflects a *general* capacity for statistical learning considers language learning to be *primarily* a process of picking up and implicitly assimilating the statistical properties of a linguistic environment. By this view, language is regarded as yet another example of a well-structured environment, and learning it draws upon the general cognitive ability to perceive and identify systematic structures and correlations. Thus, words in each language, whether morphologically simple or complex, are characterized by statistical correlations and transitional probabilities that constrain and determine their internal structure, and by correlations between their sublinguistic components and semantic features (see Frost, 2012a, for a discussion). Mastering a lexicon, therefore, involves the implicit learning of these correlations. More specifically for literacy acquisition, each language presents to the reader a writing system that is characterized by a set of correlations that determine the possible co-occurrences of letter sequences, which eventually result in establishing orthographic representations. Moreover, each writing system is characterized by a different level of consistency (i.e., high or low correlations) in the mapping of graphemes to phonemes, and these consistent mappings eventually result in mapping orthographic representations to phonological ones. Morphological structure is also reflected by systematic correlations, where repeated letter clusters consistently convey features of semantic meaning (e.g., Plaut & Gonnerman, 2000).

This approach suggests that each language implicates a differential tuning to statistical structure, given its idiosyncratic linguistic characteristics. By this view, native speakers who are proficient readers implicitly develop differential sensitivities to the statistical properties of their own language, and while learning to read in L2, speakers (and readers) acquire a new lexical system, mainly by picking up and assimilating a new set of statistical regularities. Hence, the *fundamental* cognitive faculty of implicit correlation-learning which underlies *any* form of learning plays a *primary* role in second language literacy acquisition. Note that two main factors may impede this process. First, the degree of similarity or dissimilarity between the statistical properties of the L1 and the L2 (e.g., Bialystok et al., 2005). Second, like any cognitive ability, there are individual differences in the sensitivity to the correlations in the environment. The question at hand is, therefore, whether individual differences in statistical learning predict individual differences in second language literacy acquisition. This is the focus of the present paper.

To address this question, we examined the process of assimilating the writing system of Hebrew by native English speakers. Hebrew and English were chosen for this study as an L1-L2 pair because they are contrasting languages characterized by qualitatively different statistical properties. These concern the structure of base words, given how morphological complexity is determined, and consequently, the characteristics of the writing systems. English -- an Indo-European language with a concatenated morphology -- imposes few constraints on the internal structure of base words, and in general, the predictive value of a

given phoneme regarding the identity of the subsequent one is relatively low. For example, word onsets can consist of any consonant or any vowel, and since the permissible syllables are numerous, in principle, phonemes could be located in any position within the spoken word at more or less equal probability. Prefixes and suffixes are then linearly appended to the base word and are characterized by high distributional properties (Frost, 2012a). In Hebrew, a Semitic language, words -- whether spoken or printed -- are structured very differently. Semitic words are normally composed by intertwining a tri-consonantal root morpheme, which carries the core-meaning of the word, with word-pattern morphemes -- abstract phonological structures, consisting of vowels, or of vowels and consonants, in which there are "open slots" for the root's consonants to fit into. Semitic words, therefore, have a recognizable, predictable, and well-defined internal structure. Word patterns can begin with a very restricted number of consonants, and these determine a set of transitional probabilities regarding the order and identity of subsequent consonants and vowels. Because the language is root-based, and the roots convey the core meaning of words, these need to be easily extracted and recognized by the speaker. The only clue regarding their location within the word is a well-defined phonological word structure, which on the one hand constrains dramatically the permissible phonological word-forms in the language, but on the other hand, allows the root consonants to stand out. Given the bi-morphemic structure of Hebrew words, the writing system of Hebrew consists of letters that mostly represent consonants (thereby root information), while most of the vowels can optionally be superimposed on the consonants as diacritical marks ("points"). These points, however, are omitted from most adult reading material (Frost et al., 1987; Bentin & Frost, 1987). Since the structure of spoken words is highly constrained by the permissible Semitic word patterns, readers can converge on the correct vowel configuration quite effortlessly (Frost, 1995; 2006).

In the last decade, the reading of Hebrew has been extensively investigated by Frost and his colleagues in a variety of experimental paradigms (Feldman, Frost & Pnini, 1995; Frost et al., 1997, 2000, 2005; Deutsch et al., 1998, 2000, 2003, 2005; Velan & Frost 2007; 2011). One consistent finding in all of these studies is that root primes facilitate both lexical decision and naming of target words that are derived from these roots. Moreover, proficient Hebrew readers have been shown to be tuned to the statistical properties that characterize the Semitic structure of words, so that the extraction of the embedded root consonants is fast and automatic (e.g., Frost et al., 1997; Deutsch et al, 2003), and the retrieval of vowel information is governed by the knowledge of word patterns (Frost, 2006). In other words, the sensitivity of Hebrew readers to the skewed frequency distribution of phonemes and letters in their language determines their processing of printed information; consequently, the typical reading marker of reading Hebrew -- sensitivity to the location of root consonants -- emerges (Frost, 2012; Velan, Deutsch, & Frost, in press).

In the present study we tracked the process of assimilating the linguistic properties of Hebrew by native speakers of English during their first year of learning Hebrew as a second language. We focused on *reading* as an output measure, because most research on processing morphological information in Hebrew has been carried out in the visual modality, and the markers of learning Hebrew have been mostly documented in the domain of visual word recognition. More importantly, as Hebrew print contains mainly consonantal information whereas vowels, for the most part, are not represented in print, reading Hebrew fluently cannot be carried out by simply applying grapheme-phoneme conversion rules, but requires a deep understanding of the language (Frost, 2006). Reading proficiency in Hebrew was assessed, therefore, in three tasks. The first monitored speed of decoding of pointed nonwords and reflected the assimilation of the characteristics of the Hebrew writing system. The second monitored accuracy in naming unpointed words, reflecting the implicit learning of Hebrew phonological word patterns; that is, the transitional probabilities of permissible phoneme sequences in Hebrew. The third -- cross-modal morphological priming -- directly

tapped the main marker of reading in Hebrew: the assimilation of the morphological root-based composition of words. Since our sample of English speakers, not surprisingly, presented a varied distribution of relative success in learning Hebrew, our aim was to examine whether this success (or non-success) in assimilating the writing system and the Semitic structure of words could be predicted by general statistical learning abilities that are *non-linguistic* in nature.

We therefore employed a visual statistical learning (VSL) task in which 24 relatively complex visual shapes (taken from Turke-Brown et al., 2005; See also Kim et al., 2009; Glickson & Cohen, 2011) were presented in a consecutive stream that lasted about ten minutes. The 24 shapes were organized in eight triplets, which were presented in the 10-minute stream in random order. The transitional probabilities between shapes within triplets was $p=1.0$. Participants were not told that the stream was constructed of triplets. However, following the familiarization phase, participants were presented with 32 two-alternative-forced-choice (2AFC) trials, each trial consisting of two triplets: 1) a sequence of three shapes that appeared in the stream in the original order (transitional probabilities of $p=1.0$), and 2) foils made of a sequence of three shapes that were taken from the stream, but did not appear in that order (transitional probabilities of $p=0.0$). Their success rate in distinguishing the base triplets from the foils reflected their implicit learning of the transitional probabilities of the visual shapes within the stream. The visual shapes used for the experiment and examples of the transitional probabilities of triplets are presented in Figure 1.

We then correlated relative success in the VSL task with relative success in the Hebrew reading tasks. We hypothesized that if a general statistical learning ability underlies learning to read in a new language, which is characterized by a novel set of statistical regularities, then relative success in learning the transitional probabilities of random visual shapes would predict the speed and success of learning to read a new language. Note that the theoretical implications of this possibility cannot be overestimated. It would suggest that a general non-linguistic faculty of statistical learning accounts, at least to some extent, for success in second language acquisition when L1 and L2 differ in their basic statistical properties. Such an outcome would also imply that a simple and short test involving visual shapes could predict the speed of assimilating a new linguistic environment, even before the first foreign word has been learnt.

Methods

Participants

The participants were 27 American students at the Hebrew University Overseas School (13 males, 14 females), admitted to the Hebrew Learning Program. The program consists of six levels of Hebrew proficiency, and participants were taken from levels 3 to 5, so that they had the necessary vocabulary required for participating in the experiments, yet they were not yet entirely proficient. Their mean age was 26.

Design and procedure

Each participant was tested twice (during the first and the second semester) with experimental tasks that monitored his/her learning of Hebrew, and once with the visual statistical learning task. This allowed us to track his/her individual learning curve.

Visual Statistical Learning task

As described in detail above, this task monitors participants' ability to detect the implicit transitional probabilities embedded in a continuous stream of visual shapes. Participants'

scores range from 0 to 32, given the number of correct identifications of triplets in the 32 2-A-F-C trials. Our choice of the VSL task was based on the following pretest:

Preliminary validation procedure

As with any correlation design, one general concern when interpreting a correlation between levels of performance in two tasks is that a third, perhaps trivial, capacity underlies both. The task of ruling out all possible alternative cognitive capacities is obviously infinite. However, in the present study we first aimed at mapping the relation between performance in the VSL task and performance in tasks that are traditionally taken as reliable indices of non-verbal reasoning abilities related to a general G factor, verbal working memory, and naming speed. We therefore chose: 1) the Wechsler Block Design (BD), from the WAIS-R battery, a test of spatial reasoning ability, which much like Raven's is less sensitive to verbal memory limitations, 2) Raven's advanced matrices 3) the verbal Working Memory (WM) test developed by NITE (Israel National Institute for Testing and Evaluation), and 4) Rapid Automatic Naming (RAN) with digits, letters, and objects, which is a reliable predictor of general speeded output, probably due to its sensitivity to the rate of serial encoding in working memory, 5) digit-span.

To ensure that performance in the VSL task is not confounded with these general cognitive abilities, we tested two independent samples. In sample 1, 76 participants from the Hebrew University were tested in a one-hour session with the VSL, BD, WM, and RAN tasks. In Sample 2, 56 participants from the Hebrew University were tested in a two-hour session with the VSL, Raven's advanced matrices, digit-span, WM, and RAN tasks, all in random order. The correlation matrices obtained in the two samples are presented in Table 1.¹

Learning Hebrew as L2

Three tasks served for assessing Hebrew reading proficiency: speed of decoding of pointed nonwords, naming of unpointed words, and cross-modal morphological priming.

Fast decoding of pointed nonwords

This test was borrowed from the diagnostic computer-based test battery developed by NITE in 2007 to standardize the diagnosis of learning disabilities of Hebrew speakers. The main advantage of this test is that it produces standard scores based on norms of the Hebrew-speaking population, and, therefore, it provides a frame of reference for our participants. We tested our participants twice, once at the beginning of the year and a second time at the end of the year, so that for each participant we could compute a *learning score* that was calculated by measuring his/her *improvement* in reading Hebrew between the first and the second sessions, in terms of standard deviations.

Naming of unpointed words

In this task, participants were presented with 60 unpointed Hebrew words in a naming task. Although their instructions were to read aloud the words as fast as possible, our measure of interest was the number of words that were named accurately by assigning the correct vowel configuration. This was taken as evidence for the assimilation of the word-pattern morphemes of Hebrew. As in the decoding of nonwords, our measure of learning considered the *improvement* in performance between the first and the second testing sessions.

¹We examined the correlation of performance in the VSL task with the various cognitive abilities in a pretest using independent samples of students because we were constrained by the length of testing in the experimental tasks performed by our American students.

Cross-modal morphological priming

We used the cross-modal morphological priming paradigm in order to directly assess the learning of Semitic word structure. Akin to Frost et al. (2000), participants were presented with spoken word primes via earphones while printed target words appeared on a computer screen for lexical decision. Primes and targets were either morphologically (i.e., derived from the same root), semantically, or phonologically related, and unrelated controls served as a baseline for computing the priming effect. The semantic and phonological related trials were used in this study as fillers to make the manipulation less salient. Our measure of interest was morphological root-priming. For Hebrew advanced or beginning readers, this paradigm has been shown to result in strong effects of morphological relatedness relative to simple phonological or semantic overlap between primes and targets (Frost et al., 2000, 2010).

Stimuli and details of presentation are displayed at: <http://psychology.huji.ac.il/en/?cmd=Faculty.113&letter=f&act=read&id=42~frost/>

Results

Pointed nonword decoding

The output of this computerized test is a standard score calculated relative to Hebrew speaker norms. Thus, for each participant we computed a learning score that reflected *the difference* between his/her performance in the first session (S1) and his/her performance in the second session (S2). This reflected the amount of his/her learning during the academic year. Overall mean scores at S1 and S2 were quite similar (-2.23 for S1, and -2.36 for S2), suggesting that some participants indeed improved between testing sessions, but some did not, or even scored worse on S2 than on S1. We then correlated this learning score with the score each participant obtained in the VSL task. The scatter-plot of scores is presented in Figure 2 (raw scores are presented at the link above). As can be seen in the figure, performance in the VSL task predicted the learning scores, so that participants who succeeded in the VSL task showed large improvement in pointed Hebrew nonword decoding ($r=0.57$, $p<0.002$). The correlation between the scores obtained in S1 and S2 was 0.85 .

Unpointed naming accuracy

For each participant, we monitored the number of correct and incorrect assignment of the right vowel configuration to the 60 unpointed words in S1 and in S2. We then defined the amount of learning between sessions in terms of decreased percent of errors in S2 relative to S1. Again, some participants had fewer errors in S2 than in S1, demonstrating an assimilation of the word patterns of Hebrew, whereas some did not improve or even deteriorated. Figure 3 presents the scatter-plot of the VSL scores with the learning scores. As with pointed nonword decoding, the correlation was robust and significant ($r=0.43$, $p<0.028$). The correlation between the scores obtained in S1 and S2 was 0.63 .

Morphological priming effects

Overall response latencies were faster in S2 relative to S1 due to increased proficiency, and therefore, the priming effects were proportionally reduced. Given this classical pattern of scaling, an “improvement score in priming” could not be unequivocally calculated. Figure 4, therefore, presents the scatter-plot of the morphological priming effects along with scores in the VSL task, for S1 and S2 separately. The measures in the two sessions consist, therefore, of independent validation of our predictions. Similar to the findings with pointed nonword decoding and naming of unpointed words, scores in the VSL task were highly correlated with the amount of priming, so that higher scores in VSL predicted larger root morphological-priming effects ($r=0.57$, $p<0.002$ for S1, $r=0.44$, $p<0.02$ for S2).

As the cross-modal priming experiment also included a semantic relatedness condition that served for the present purpose as a filler, we examined the correlation between the VSL task and the semantic priming effects. The correlations were low and non-significant ($r=0.15$, $p<0.45$; $r=0.26$, $p<0.19$), and the respective scatter plots in S1 and S2 are presented in Figure 5. Thus, the VSL task does not seem to be correlated simply with better performance or with any priming effect, but seems to be a predictor of the reading markers related to the *structural* properties of Hebrew as a Semitic language.

Discussion

This study examined whether differential ability to detect the implicit transitional probabilities of visual shapes in a continuous stream predicts differential ability in literacy acquisition in a second language, when L1 and L2 present contrasting linguistic environments in terms of statistical properties. We therefore tracked the learning process of Hebrew, a Semitic language, in native speakers of English, an Indo-European language. Our results seem unequivocal. Participants who scored well in the VSL task, that is, picked up the implicit statistical structure embedded in the continuous stream of visual shapes, on average, scored well on the tasks that monitored the assimilation of the Semitic structure of Hebrew words. We should note that this correlation was exclusive to morphological priming, the typical finding with Hebrew readers, and was not found for semantic priming, suggesting that it is related to learning the structural Semitic properties of the language.

Admittedly, the present pioneering study is based on a sample of Hebrew learners that is not large ($n=27$), and a possible concern when relatively small samples are employed in correlation designs is that one or two deviant observations could drive the correlation. The scatter-plots in Figures 1–4 clearly demonstrate that this is not the case. The distribution of observations in the three tasks systematically shows that the higher the VSL scores of our participants, the higher their scores for learning Hebrew.² Moreover, as performance in the VSL task is not correlated with general performance factors such as Block-Design, working memory, or RAN, our findings seem to suggest a genuine link between statistical learning of visual shapes and learning to read in a second language. Converging preliminary data reported recently with learners of Chinese as a second language (Wu et al., 2012) suggest that our findings are not specific to learning Hebrew as L2. Similar to the present results, Wu et al. (2012) found that the level of Chinese literacy of readers of alphabetic orthographies could be accurately predicted by their performance in the VSL task. This outcome suggests that our findings extend to other languages and writing systems.

Admittedly, coming from abroad to study Hebrew, our participants were likely to be motivated to learn Hebrew, and this may have had some impact on their rate of learning. Also, our design did not allow us to statistically compare the power of the VSL task in predicting L2 learning outcome relative to other general cognitive abilities. Nevertheless, the observed systematic and significant correlation between the VSL task and L2 literacy acquisition has considerable theoretical implications. It suggests that a common faculty underlies performance in a task that taps the implicit learning of transitional probabilities of a stream of visual shapes, and a series of measures that tap the acquisition of the deep linguistic structures characteristic of a given language. This finding points to the possibility that a unified and universal principle of statistical learning can quantitatively explain a wide range of cognitive processes across domains, whether they are linguistic or nonlinguistic (Frost 2012a, b). Note that similar claims have been advocated by Ahissar and her

²Note that the observed correlations between VSL and reading scores are partly driven by a seeming “decrease” of reading scores over time for some learners. This, however, probably reflects a simple regression to the mean of some slow learners, who obtained in T1 a score slightly better than their actual performance, rather than a true decline in performance.

colleagues, who demonstrated that a general cognitive factor, mainly sensitivity to the statistics of simple auditory stimuli, is related to language aptitude (e.g., Ahissar, et al., 2006).

We entertain then the suggestion that cognitive systems are tuned to seek correlations in the environment, and that the implicit assimilation of event co-occurrences is the basis for many different types of learning. The linguistic environment is no exception to this basic principle. Languages and their writing systems are characterized by idiosyncratic correlations of form and meaning, and these are picked up in the process of literacy acquisition, as they are picked up in any other type of learning, for the purpose of making sense of the environment.

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8 Triplets

8 Foils

Figure 1.
The 24 visual shapes employed in the VSL task and examples of triplets and foils

Figure 2.
Scatter-plot of scores in the VSL task with improvement of standard scores of nonword decoding from S1 to S2

Figure 3.

Scatter-plot of scores in the VSL task with improved percent of naming accuracy of unpointed words from S1 to S2

Figure 4.
Scatter-plot of the VSL task with morphological priming scores in the first and second session (S1, S2)

Figure 5.
Scatter-plot of the VSL task with semantic priming scores in the first and second session (S1, S2)

Table 1
Correlations between the Visual Statistical Learning (VSL) task and general cognitive abilities

	Sample 1 (n=76)				Sample 2 (n=56)	
	Block Design	Verbal Working Memory (VWM)	Rapid Naming (RAN)		Raven Advanced Progressive Matrices	Digit Span
			Digits	Objects	Letters	
Correlation with VSL	0.19	0.15	0.18	0.27	0.02	0.24
p value	0.1	0.2	0.12	0.02	0.86	0.07