Identification of words’ grammatical functions in Hebrew: Electrophysiological evidence

Mark Leikin

Identification of words’ grammatical functions in Hebrew: Electrophysiological evidence

INTRODUCTION

The paper presents the results of two electrophysiological experiments that focused on processing words’ grammatical functions during reading of Hebrew sentences by normal and dyslexic readers.

According to many psycholinguists (e.g., Ferstl & Flores d’Arcais, 1999; Frazier, 1987), sentence comprehension is a complex task that involves a number of cognitive processes, and refers to various information sources. In particular, the act of sentence understanding requires the processing of words so that they are assigned an immediate syntactic categorization, making possible the attribution of words’ grammatical functions. This in turn is used to construct a single preliminary phrase structure (Mitchel, 1994). Common to most models of syntactic parsing (e.g., Frazier, 1987; Altmann, Garnham, & Dennis, 1992; Tanenhaus & Carlson, 1989) is the view that syntactic categorization is performed in the first stage of the parsing. The controversy concerning this stage is whether the parser uses syntactic information exclusively, as posited by the garden path theory (e.g., Frazier, 1987), or whether non-syntactic content may also influence the first pass, as proposed by the interactive model (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994).

Theoretically, each of the words’ grammatical functions contributes differently to sentence comprehension. In this case, two main grammatical functions (i.e., subject and predicate) must play a central role in the sentence processing, and identification of these core points of syntactic structure seems a very important task. Contemporary literature suggests that such identification may be possible by reference to different sources of information, such as word order, inflectional morphology, and the lexical-
morphological properties of the words (Perfetti, 1999; Ferstl & Flores d’Arcais, 1999). However, various sources of information may be expected to contribute differently to this process in different languages. In English, for example, the syntactic order of the sentence components is usually fixed. Word order in the English language is therefore highly important for sentence processing (MacDonald, Bock, & Kelly, 1993). It may be otherwise in such languages as Hebrew, in which the syntactic structures are not necessarily in fixed order.

**Hebrew language**

In general Hebrew is closer to languages with pragmatic word order than to those with grammatical word order (Berman, 1985). The most characteristically Semitic feature of Hebrew is its derivational morphology (Ephratt, 1985). Most content words can be further broken down into two basic components: root and pattern. The root, being the semantic core of a word, is an ordered sequence of consonants (usually three), while the pattern is a sequence of vowels or vowels and consonants (e.g., GiBoR, ‘hero’). Semantic information conveyed by the pattern is considerably less transparent. The verb patterns differ from the patterns of other content words. Verbs are formed according to seven patterns (binyanim, ‘conjugations’) while nouns and adjectives may occur in any of several dozen different patterns (mishkalim, ‘declensions’). The verb patterns denote such predicate-argument relations as transitivity, voice, causativeness, etc. The noun patterns specify lexical classes (e.g., action nouns, agents, and instruments). Apart from a verb’s appearance in the form of infinitive, it is inflected by tense, gender, number, and (in all but present tense) person. So the verb provides some information about the subject, and in certain cases may express subject information. Usually the verb also determines selection of the prepositions, which in turn frequently appear in the role of
object marker. Accordingly, the verb provides a great deal of information that proves essential for sentence understanding.

In Hebrew, then, recognition of lexical-morphological characteristics of the words (word-form information) seems to make available important syntactic information. ‘Lemma information’ (Levelt, 1989), detailed lexical-syntactic information about the word, may be used by the parser to achieve words’ syntactic categorization (Mitchel, 1994). For example, it may use the information about argument structures that different verbs can take part in and the thematic roles of syntactic arguments (e.g., necessity for a subject and direct object). Accordingly, by using the lexical entry for a word along with other sources of information (e.g., incremental presuppositions during word-by-word reading) the parser may attribute grammatical functions to words in sentences.

Note, however, that this issue has been poorly studied not only in Hebrew but also in other languages. In addition, most evidence in this field has been derived from behavioral measures (e.g., reaction times), which provide information about the cognitive processes only at the conclusion of the processing sequence. In this context, employment of the technique of Event-Related Potentials (ERP) appears extremely promising because it reflects the patterns of neuronal activity evoked by different stimuli and makes it possible to track the continuity of on-line cognitive activity during language processing (see Kutas & Van Petten, 1994, for review).

**ERP study of contribution of words’ grammatical functions to sentence processing**

Current research has demonstrated that ERP measurement has useful applications in reading research (Bentin, 1989). ERP components can indicate the point in time at which some variable exerts its effect on information processing. ERPs extracted to assess on-line language processing are obtained by the averaging of the brain responses to a number of equivalent trials in a given experimental condition. Areas of brain
specialization can be identified by observation of variations on amplitude and latency of ERP components across different scalp locations (e.g., Halgren, 1990).

The ERP components found most relevant in the context of reading are N100-P200, P300, and N400 (Kutas & Van Petten, 1994; Regan, 1989). Respectively these components yield information about the timing (latencies) and intensity (amplitudes) of stimulus evaluation, response selection, and lexical integration. In this case, N100-P200 is held to be related to perception (Regan, 1989; Brandeis & Lehmann, 1994). P300 occurs in response to rare and relevant events, and appears to be associated with stimulus classification and updating in short-term memory (Donchin, 1981; Halgren, 1990). N400 is regarded as a manifestation of lexical integration (Kutas & Van Petten, 1994). Recently, however, one more ERP component has been identified as probably related to syntactic processing. This is P600, sometimes labeled Syntactic Positive Shift (Friederici & Mecklinger, 1996; Osterhout & Holcomb, 1995).

Traditionally, ERP in language-related studies has been conducted by means of different linguistic violations (Kutas & Van Petten, 1994; Friederici, 1999). However, it has been suggested (Van Petten, 1995) that while violations are an excellent way of eliciting large and robust ERP effects, this does not mean that ERP components are a specific or unique reflection of any given linguistic errors. Therefore, it is valuable to study not only the violations but also the processing of normal word strings in relation to linguistic characteristics of the words. Recent studies by Breznitz and Leikin (Breznitz & Leikin, 2000; Leikin & Breznitz, 1999, 2001) employed just this approach for the examination of contribution of words’ grammatical function to sentence processing.

The first of these studies (Leikin & Breznitz, 1999) investigated the way in which the grammatical roles of words influence sentence processing among normal adult readers. Brain activity was examined during participants’ processing of various parts of
sentence. The obtained effect concerned the amplitudes and latencies of the N100 and P300 ERP components. Changes in these components were associated with processes contributing to the first stage of syntactic parsing. That is, they seemed to be sensitive to processes of identification and analysis of the target words in accordance with their grammatical roles. In this case, N100 was suggested to be related to the search process and identification of core points in the sentences requiring information and focusing of attention. Simultaneously, P300 was associated with operations involving classification of target words and updating in short-term memory. The major effect was manifested by differences among three central parts of the sentence (subject, predicate, and direct object), with the largest differences observed for the predicate. Accordingly, it was suggested that among normal readers, processing different sentence elements might be affected by the grammatical roles of target words. It was also found that Hebrew-speaking readers tended to utilize the predicate-oriented morphologically based strategy for processing of words' grammatical functions. The findings showed that in Hebrew, word order did not significantly influence the process of identification of grammatical functions, or at least played a less important part. In this context, it was proposed (Breznitz & Leikin, 2000) that dyslexic readers may experience certain difficulties in usage of the predicate-oriented strategy.

**Dyslexia and syntactic abilities**

The role of syntactic abilities in dyslexia has been widely discussed over the past decade (Badian, Duffy, Als, & McAnulty, 1991; Gottardo, Stanovich, & Siegel, 1996; Tunmer & Hoover, 1992). Research has provided considerable evidence of a link between syntactic processing and reading skills. Poor readers differ on a number of syntactic processing tasks: sentence correction, grammatical acceptability, sentence judgment, etc. (Badian et al., 1991; Gottardo et al., 1996; Tunmer & Hoover, 1992). Even so, the role
of syntactic processing deficit in dyslexia remains unclear. Some researchers claim a
dissociation between reading skills and a generalized language factor (e.g., Badian et al.,
1991). Other researchers maintain that deficits in various phonological processes affect
different aspects of language processing (e.g., Gottardo et al., 1996). In this context, it
was proposed (Breznitz & Leikin, 2000) that if syntactic processing ‘weakness’ is
involved in dyslexia it may be reflected by variations in ERP measures.

Until recently there have been few studies of dyslexia by ERP methods. However,
available evidence from electrophysiological studies indicates that specific processing
stages are affected in developmental dyslexia. Differences in information processing are
reflected in variations in the spatial patterns of neural activity in the brain as well as an
altered time course (Brandeis, Vitacco, & Steinhausen, 1994; Breznitz, 1999; Riccio &
Hynd, 1996). For example, a number of word recognition studies found differences in
early and later ERP waves between dyslexic children and their normally reading
controls, although the available data are not clear-cut (Brandeis et al., 1994; Riccio &
Hynd, 1996). Stelmack et al. (Stelmack, Saxe, Noldy-Cullum, Campbell, & Armitage,
1988) found that in contrast to normal readers, reading-disabled boys exhibited greater
P200 amplitudes during a visual word recognition task. Taylor and Keenan (1990)
obtained the opposite results during a lexical decision task: in dyslexic children P200s
were observed of lower amplitude than in normally reading children. Evidence of longer
N200 latencies among dyslexic children was also obtained. These investigators further
observed reduced P300 amplitudes and longer P300 latencies in dyslexic children, as
opposed to Stelmack et al. (1988) who found no evidence of P300 differences between
dyslexic and control groups.

In Breznitz and Leikin’s study (2000), the process of identification of words’
grammatical functions was investigated in dyslexic readers by the same method as in
the study with normal readers (Leikin & Breznitz, 1999). As in normal readers, significant differences in the contribution of words’ grammatical functions to sentence processing were observed in the dyslexic group. However, the results revealed substantial differences in ERP measures between two readers’ groups. Compared with normal readers, dyslexic readers exhibited consistently higher amplitudes and longer latencies in both the N100 and P300 ERP components for the subject. Significant though less consistent ERP variations were observed for other sentence elements. On the whole, the results manifested readers’ tendency to use a simpler mode of identifying words’ grammatical functions, namely word order. While this strategy is not the most efficient for linguistic processing in Hebrew (Leikin & Breznitz, 1999), it is typically used during the early stages of language development among Hebrew-speaking children (Sokolov, 1984). However, even this strategy demanded more significant effort in the brain during processing information, as N100 and P300 amplitudes reflected it (cf. Taylor & Keenan, 1990). In turn, increase of latencies demonstrated a slower processing speed (e.g., Breznitz, 1999). Accordingly, these results were accounted as confirmation of the hypothesis maintaining a syntactic processing ‘weakness’ in dyslexia.

Thus, the findings (Breznitz & Leikin, 2000; Leikin & Breznitz, 1999) showed that in both normal and dyslexic readers, the variations in ERP waves were due to words’ specific grammatical functions. According to this conception the obtained patterns of brain activity seemed to reflect a process of syntactic parsing (first pass), namely a process of identification of words’ grammatical roles, and the application of this information to further syntactic processing of the sentence. In both groups, identification of grammatical functions was by means of the lexical-morphological properties of the words (word-form information), although dyslexic readers were apparently also affected by word order. Accordingly, the proposed syntactic processing
‘weakness’ in dyslexia was interpreted in terms of difficulties in identification of words’ grammatical functions by means of words’ lexical-morphological properties. However, these hypotheses required further examination. The previous results were potentially confounded by lexical factors (e.g., verbs as opposed to nouns). Accordingly, the point of special interest was the additional influence on sentence processing of such factors as word-order information and lexical-morphological properties of the verb as against to noun. To this end, it was proposed to utilize the same methodological paradigm as in the previous study (Leikin & Breznitz, 1999). However, the stimuli material would be changed so that the sentences would include common invariable words having interchangeable grammatical functions and position in the sentences (Experiment 1). This would permit a purer test of sentence processing, not confounded by lexical factor or word position. It was expected that the pattern of brain activation in accordance with words’ grammatical roles would be changed in this new experimental paradigm. It was also suggested that reduction of lexical-morphological differences among three sentence elements would cause a shift to another strategy of identification of words’ grammatical functions.

Another point of interest concerns the possibility to change processing strategy under the influence of any external factor. In this connection it was suggested that the effects of accelerated reading rate on syntactic processing be examined. Reading rate is crucial to reading performance (Carver, 1990; Stanovich, 1981). Not only does a faster reading speed characterize better readers, but increasing reading speed can also improve reading proficiency (Breznitz, 1997). Breznitz (1987) suggested that reading rate could function as an independent variable capable of influencing the quality of reading performance.
Leikin and Breznitz (2001) investigated the way in which fast-paced reading rate influences processing of the words’ grammatical functions among normal adult readers. The same method applied in the previous study (Leikin & Breznitz, 1999) was utilized in this case, with acceleration in the rate of word presentation. The results showed that an accelerated reading rate influenced processing of words’ grammatical functions. The tendency to favor the predicate-oriented strategy was preserved but the new strategy that appeared was more akin to that of word order. This was caused by facilitation in processing of most of the sentence elements. A significant increase of amplitudes and decrease of latencies for both the N100 and P300 ERP components expressed this effect. Along with improvement in sentence comprehension these findings seemed to demonstrate that the influence of fast-paced reading rate on the processing of the words’ grammatical functions was one more factor relevant to the improvement of reading comprehension and change of processing strategies. Accordingly, the results showed that reading rate might influence such high-level processes as identification of words’ grammatical functions.

To judge these results along with data on the contribution of accelerated rate to improvement of reading quality in dyslexic children (Breznitz, 1997; Breznitz, 1999), it was suggested that fast-paced reading rate may significantly influence sentence processing in dyslexic readers also (Experiment 2).

**METHOD**

*General characteristics*

In both experiments, participants were 20 dyslexic and 20 normally reading male university students aged from 18 to 27 years (mean age 24 years). Dyslexic readers were selected who matched the controls on measures of nonverbal IQ (Raven & Court,
native Hebrew speakers, right-handed, and displayed normal vision in both eyes. The dyslexic readers were recruited from the Student Support Service at the University of Haifa, Israel. These were subjects with greatly compensated dyslexia. They were diagnosed as dyslexic in childhood and as impaired readers in the present. Evaluation of reading performance at the Support Center (Haifa Psychological Services, 1995) indicated that these participants continued to have impaired reading skills. For example, they were about 20% slower in oral reading, and achieved about 17% lower comprehension scores in oral and silent reading than their normal controls.

**Electrophysiological Baseline Measures**

*Target detection tasks* were administered to habituate the participants to the experimental situation and to verify correct response in terms of brain activity (P300 component). For the auditory modalities, stimuli were a 1000 Hz tone and a 3000 Hz tone presented consecutively over a PC speaker. For the visual modalities, stimuli were two Hebrew block letters, .64 cm. high presented successively at the center of a computer screen. Stimulus presentation time depended upon the latency of the participants' responses. Stimuli were presented for a duration of 250 ms at an ISI of 700 ms. The participants were required to count the target stimuli (20% of the time, n=20) and ignore the non-targets (80%, n=80).

*Procedure.* The participants were seated in a quiet room, 1.5 meters away from an IBM-PC computer screen. The stimuli were presented in white over a gray background. The participants were instructed to remain quiet during the testing session, to refrain from moving, and to avoid excessive eye movements and blinking as much as possible.

The items appeared one at a time on the computer screen. The participants were instructed to begin reading the item immediately on its appearance on the screen. After
reading the item, they pressed a button on the keyboard. When the participant had finished reading the items, the multiple-choice questions appeared consecutively. The answer has to be selected by pressing a number on the keyboard (1-4). Measures of comprehension and reaction time were determined for each reading item. The stimuli were counterbalanced across two experimental conditions in Experiment 1 and across three conditions in Experiment 2. The experimental conditions were as follows:

Self-paced, Full-screen presentation. In this condition, each item appeared in its entirety on the computer screen. The behavioral measures derived in this condition were used as the basis for presentation rate in the second condition.

Self-paced, Window presentation (with electrophysiological measures). The sentences appeared word-by-word. As word presentation rates were calculated for each individual reader, subsequent presentation rates differed across participants.

Fast-paced, window presentation (with the electrophysiological measures): only for Experiment 2. The words in each sentence appeared one at a time. Words were presented at the fastest average per-word rate exhibited in the first self-paced condition.

Twenty-two channels of EEG activity were acquired, by means of a Bio-Logic Brain Atlas III computer system with brain mapping capabilities. This system used a bandpass of 0.1-70 Hz interfaced with a 20-channel 12-bit A/D converter. The potentials were sampled at a rate of 250 Hz (dwell time = 4.0 ms) beginning 100 ms before stimulus onset. A full array of electrodes (19 scalp electrodes) was placed according to the International 10/20 system, with use of an Electro-cap. During data collection electrode impedance was kept below 5 K. All were referenced to an electrode on CVII (the seventh vertebra) and grounded to Fpz. In addition, one electrode was applied diagonally below the left eye to monitor eye movements.
The trial onset was marked on the Oz channel of EEG via a positive polarity 5 millivolt (mV) pulse delivered from an IBM-PC 586 computer. Signal averaging of the raw EEG data was performed off-line. EEG data were separated into discrete trials. After the eye movement correction, averages of the individual trials were determined. There were three (Experiment 1) or five (Experiment 2) average trials, one for each of the target sentence elements across items per participant. Only single trials associated with correct responses were averaged to obtain the Evoked Potentials. ERP measures were determined relative to the pre-stimulus baseline. ERP peak latencies were measured from stimulus onset. Amplitudes were measured relative to the mean voltage of each channel.

EXPERIMENT 1

Experiment 1 examined effects of lexical factor and word position in the sentence on processing words’ grammatical functions among normal and dyslexic readers. Experimental stimuli were 15 groups of sentences. Each group comprised three sentences, 5-8 words in each. These were regular declarative Hebrew sentences in SVO syntactic order. Each sentence included three grammatical functions under study: subject, predicate, and direct object. Stimuli included the same words (nouns) having interchangable grammatical functions and position in the sentences. In each group of three sentences the target word appeared at the beginning of the sentence (subject), in the intermediate position (predicate), and in the terminal position (object). For example, hakhavila hekhila et hamutsarim hashonim ('The package contained the various products'); hakuufsa hagdola haita khavila ('The big box was a package'); anakhnu sholkhim et hakhavila lekhaverim ('We are sending the package to friends'). The words were selected on the basis of similar frequencies in Hebrew (Balgur, 1968) and their length. For each sentence there were two multiple-choice questions.
ERP measures of brain activity were recorded for three target sentence elements in each sentence for each participant when reading in a self-paced condition.

Results and discussion

Within-Group Comparisons

In both groups of participants, N100/P200, P300, and P600 ERP waves were identified for subject, predicate, and object in each sentence. Table 1 presents means and SD for ERP latencies and amplitudes for the three sentence elements.

Table 1 about here.

In dyslexic readers, a Repeated Measure MANOVA revealed a significant main effect for the three studied sentence elements in latencies of P200, F(3,16)=5.3 p<.01, P300, F(3,16)=6.2 p<.01, and P600, F(3,16)=3.3 p<.03. The effect stemmed from significantly longer ERP latencies for object (P300 and P600) and subject (P200). No significant effect was found among the studied words in ERP amplitudes.

In the normal readers’ group, data revealed significant main effect for the three sentence elements in latencies of P200, F(3,16)=4.5. p<.03, P300, F(3,16)=12.2 p<.004, and P600, F(3,16)=9.0 p<.01. The effect stemmed from significantly longer P200, P300, and P600 latency for subject. No significant effect was found among the three sentence elements in amplitudes of identified ERP components.

Between-Group Comparisons

GLM-Manova was carried out in order to determine the differences between the two groups of readers in ERP amplitudes and latencies.

Amplitudes. Data revealed a significant group effect for predicate in two ERP components: P200, F (19,35) = 2.9, p < .05, and P300, F (19,35) = 3.1, p < .01. The
dyslexic readers exhibited significantly higher amplitudes than the controls in both cases.

Latencies: Data revealed significant group effect for subject in two ERP components: P200, $F (19,35) = 4.2, p < .01$, and P600, $F (19,35) = 5.8, p < .008$. Likewise, data revealed a significant group effect for object in P300, $F (19,35) = 4.2, p < .003$, and P600, $F (19,35) = 4.5, p < .002$, and for predicate in P600, $F (19,35) = 3.8, p < .003$. All ERP latencies were significantly longer in the dyslexic readers than in the controls.

Thus, the results revealed significant differences in ERP measures between dyslexic and normal readers. Compared with controls, dyslexic readers exhibited consistently higher amplitudes and longer latencies of P200, P300, and P600 in all sentence elements. However, changes of activation patterns were different for different sentence elements in between-group as well as within-group comparisons. These findings cannot be attributed to lexical properties of the words or to their position in the sentence since these factors were controlled in the experiment. Increase of ERP amplitudes and latencies in dyslexic readers is only partly in line with the data obtained by Taylor and Keen (1990) and Stelmack et al. (1988) in lexical decision and visual word recognition tasks, respectively. However, these results confirm the previous findings concerning the increase of ERP amplitudes and latencies during processing of words’ grammatical functions by dyslexic readers (Breznitz & Leikin, 2000). This effect, which consistently appeared in several ERP components in the two experiments, suggests that different processes occurred for some sentence elements in the dyslexic population.

Higher amplitudes are thought (Taylor & Keenan, 1990) to represent more effort in the brain during processing information. In turn, longer latencies are interpreted as a reflection of a slower processing speed (Breznitz, 1999). Accordingly, the results seem
to demonstrate that processing of words in accordance with their grammatical functions is slower in dyslexic readers and requires more substantial effort. Note, however, that increase of intensity and timing was dissimilar in different ERP components and for different sentence elements. An inconsistent mode of activation in different ERP components appears to be characteristic for dyslexic readers, as indicated in the previous study (Breznitz & Leikin, 2000). At the same time, differences between sentence elements seem to reflect the effect of words’ grammatical functions (Leikin & Breznitz, 1999). Accordingly, substantial dissociation between normal and dyslexic readers referring to processing of different grammatical functions may be interpreted in terms of relative difficulties of these grammatical functions.

In this case, the results in ERP latencies resemble to a certain degree the previous findings (Breznitz & Leikin, 2000), which reflected the dyslexic readers’ tendency to utilize word-order strategy for processing grammatical functions. That is, the differences in processing the grammatical functions were at least partly caused by their position in the syntactic order. However, the results in P200 and P300 amplitudes were different. This fact may reflect a significant increase in difficulties in processing the predicate under new experimental conditions. Failure fully to use either of the two possible processing strategies probably caused in dyslexic readers more effort in the processing of verb information (in cases where the verb appeared in the predicate role). Thus, the obtained results would appear to confirm the hypothesis maintaining a syntactic processing ‘weakness’ in dyslexia.

Differences between dyslexic and normal readers were also revealed in the activation patterns, namely processing strategies (the descending order of grammatical functions in accordance with level of their activation), that they used. The present study found modification of activation patterns in normal and dyslexic readers as compared
with those of the previous research (Leikin & Breznitz, 1999; Breznitz & Leikin, 2000). In the previous experiments two distinct patterns of brain activation were identified. The first, a predicate-oriented pattern (predicate > subject > object ≥ modifier = preposition), was more evident in normal readers. The second, a word-order pattern (subject > predicate > object = preposition = modifier), was demonstrated by dyslexic readers. By contrast, the patterns of brain activation obtained in the present study were neither predicate-oriented nor fully word-order ones, and were expressed by latency measures alone. In the normal readers’ group this related to significantly longer ERP latencies for the subject (subject > predicate = object). The same pattern was also displayed by P200 latency in the dyslexic group while the P300 and P600 latency changes reflected another pattern (object > subject = predicate). Thus, the patterns of brain activation were partly different in dyslexic and normal readers. In turn, these data confirm the assumption (Breznitz & Leikin, 2000) that like normal readers, dyslexic readers identify words’ grammatical functions at least partly through the words’ lexical-morphological properties, being simultaneously affected by word order also. Note that dyslexic readers seemingly showed just this effect for predicate (relative increase of P200 and P300 amplitudes).

We speculate that modification of activation patterns was due to the character of the stimuli sentences in the new experiment. Previous data (Leikin & Breznitz, 1999; Breznitz & Leikin, 2000) were obtained by means of the stimuli sentences, which included verbs in the function of predicate as well as different prepositions. In the present study, one third of the sentences were verbless. Lexical-morphological characteristics of words that played different grammatical parts, were equalized to a certain degree. Also, only the preposition *et* as the object marker appeared in the sentences. Accordingly, the obtained activation pattern may be explained by reduction
of lexical-morphological differences among the three sentence elements. This seems especially critical for verbless sentences. Absence of the verb might cause a relative decrease of brain activation in response to predicate, and equalization of intensity and timing measures for predicate and object. This appears to confirm the significance of the verb for processing of Hebrew sentences (Leikin & Breznitz, 1999).

Specific morphological features characterize the Hebrew verb. Such characteristic word-form information simplifies recognition of the verb, but on the other hand, morphological complexity and informativeness of the Hebrew verb seem to demand higher intensity of attention and more working-memory resources for activation of lemma information. This effect was shown in the previous study (Leikin & Breznitz, 1999) by an increase of N100 and P300 amplitudes and latencies.

Thus, in normal readers, the predicate lost its morphological distinctness, and therefore changed its properties in terms of ERP measures, rather than the subject itself causing these changes. In turn, the presence of the prepositional object marker facilitated identification of object (Sokolov, 1984). As relative ease of the identification process probably means an acceleration and simplification of information processing, this would cause reduction of intensity and timing.

As for dyslexic readers, the proposed syntactic processing ‘weakness’ was interpreted in terms of difficulties in identification of words’ grammatical functions by means of words’ lexical-morphological properties (Breznitz & Leikin, 2000). If this holds true, then in contrast to normal readers, the processing of the object may be complicated because of the presence of an additional morphological characteristic, the prepositional object marker. Note that prepositions caused very prominent activation in another study with dyslexic readers (Breznitz & Leikin, 2000).

Thus, the results seem to confirm the hypothesis (Leikin & Breznitz, 1999) that
Hebrew readers use lexical-morphological properties of the words to identify their grammatical roles. At the same time, the results demonstrated that there were significant differences in sentence processing between normal and dyslexic readers as reflected by ERP measures. On the one hand, the dyslexic readers demonstrated higher ERP amplitudes and longer latencies, and this probably reflected relatively slow processing rate and significant effort during processing of specific information in the brain. On the other hand, the dyslexic readers tended to use another strategy for identification of words’ grammatical functions: word-order strategy.

**EXPERIMENT 2**

The objective of *Experiment 2* was to examine how an accelerated reading rate influences processing of words with different grammatical functions.

**Method**

*Stimuli* were three forms of a reading comprehension test from *The Israeli Standard Achievement Test for Higher Education* (1996). Each form comprised 17 items, with 7-9 words in each. The items were regular declarative Hebrew sentences in SVO syntactic order. Each sentence included the five sentence elements under study: subject, predicate, object, modifier, and preposition (as object marker). In all sentences the target words appeared in constant order, but the ordinal position of each word varied to some extent from sentence to sentence. The target words were selected on the basis of similar frequencies in Hebrew (Balgur, 1968) and their length. For each sentence there was one multiple-choice question.

ERP measures of brain activity were recorded for each target element in each sentence for each participant when reading in a self- and fast-paced condition.
Results and discussion

A 2 x 2 repeated measure MANOVA [Groups (dyslexic readers x controls) x Pace (self-x fast-window presentation)] was conducted to determine the differences between two groups of readers in comprehension and reading time as well as in the ERP amplitudes and latencies. Results indicated a significant group effect in reading comprehension, $F(2,38)=4.7 \, p<.04$ and reading time, $F(2,38)=10.1 \, p<.001$. Comprehension score was lower and reading time was longer for the dyslexics than for the controls (Table 2). Results also indicated Group x Pace interaction for comprehension, $F(2,38)=6.8 \, p<.003$ and for reading time, $F(2,38)=9.7 \, p<.001$. Both groups of readers improved their comprehension and reading time scores during reading acceleration (Table 2). However, dyslexic readers derived the greatest benefit from fast-pace reading.

---

Table 2 about here.

---

Thus, the comprehension scores indicated a marked discrepancy between reading ability of dyslexic readers and their performance when they read at their own fastest rate. These findings reproduced the data obtained in previous studies in reading acceleration (Breznitz, 1997; Leikin & Breznitz, 2001). Improved comprehension was already ascribed (Breznitz, 1997) to the positive influence of the increase in processing speed on reading ability to allocate information processing resources. The ERP data obtained in the study seemed to confirm these assumptions.

 ERP Data

Tables 3 and 4 summarize the results of normal and dyslexic readers in terms of ERP amplitudes and latencies in both the self- and fast-paced conditions. N100, P300, and N400 waves were identified in both the self- and fast-paced
conditions among dyslexic and normal readers.

-----------------------

Table 3 about here.

-----------------------

For *N100 amplitudes*, data revealed a significant group effect for subject
\(F(19,21)=5.2, p<.003\) and predicate, \(F(19,21)=2.7, p<.04\). Dyslexic readers exhibited consistently higher amplitudes in both reading conditions than the controls. Results indicated a significant Group x Pace interaction for subject, \(F(19,21)=3.7, p<.01\) and predicate, \(F(19,21)=3.2, p<.01\), respectively. The amplitudes in fast-paced as compared with self-paced reading increased significantly among dyslexic than in controls.

For *N100 latencies*, data revealed a significant group effect for subject,
\(F(19,21)=3.8, p<.01\) and predicate, \(F(19,21)=2.8, p<.04\). This effect was due to considerably longer latencies in both reading conditions among dyslexic than among normal readers. Results also displayed a significant Group x Pace interaction for subject, \(F(19,21)=3.4, p<.01\). Compared with the self-paced condition, the latencies in the fast-paced condition were far shorter in dyslexic than in controls for the subject.

No significant main effect of group was found in N100 amplitude and latency for object, modifier, and preposition.

-----------------------

Table 4 about here.

-----------------------

For *P300 amplitudes* there was a significant group effect for subject,
\(F(19,21)=2.9, p<.02\), predicate, \(F(19,21)=2.4, p<.05\), object, \(F(19,21)=2.9, p<.05\), and modifier, \(F(19,21)=2.4, p<.05\). Results indicated a significant Group x Pace interaction for subject, \(F(19,21)=4.0, p<.009\), predicate, \(F(19,21)=5.0, p<.004\), object,
The P300 amplitudes during the fast-paced reading condition as compared with the self-paced condition increased significantly in dyslexic readers than in controls. For P300 latencies, data revealed a significant group effect for subject, \( F(19,21)=2.4, p<.05 \), predicate, \( F(19,21)=3.5, p<.03 \), object, \( F(19,21)=3.5, p<.02 \), modifier, \( F(19,21)=3.2, p<.02 \), and preposition, \( F(19,21)=4.7, p<.004 \). This effect was due to significantly longer latencies in both reading conditions in dyslexic than in normal readers. Results also indicated a significant Group x Pace interaction for subject, \( F(19,21)=3.1, p<.05 \), predicate, \( F(19,21)=3.7, p<.04 \), object, \( F(19,21)=5.0, p<.003 \), modifier, \( F(19,21)=4.8, p<.004 \), and preposition, \( F(19,21)=3.2, p<.02 \). Compared with the self-paced condition, the latencies in the fast-paced condition were far shorter in subject, predicate, and object in dyslexic readers than in controls.

No significant differences were found between the two groups in N400 amplitudes and latencies.

Thus, in the self- and fast-paced conditions, the words’ grammatical functions contributed differently to sentence processing as reflected by ERP measures. However, in accelerated reading, there was a significant decrease of latencies and an increase of amplitudes for both N100 and P300 ERP components. The shortening of ERP latencies was in line with previous data of Breznitz et al. (1994). The increase of amplitudes was not previously reported. Even so, there was apparently no contradiction between the results of two studies because their methods were different. Dyslexic readers already displayed higher N100 and P300 amplitudes and longer latencies than normal readers in the self-paced condition (Breznitz & Leikin, 2000).

By contrast, in the fast-paced condition, shortening of ERP latencies followed higher amplitudes. This suggested that a faster reading rate might accelerate the
processing speed of syntactic parsing (Leikin & Breznitz, 2001). In turn, acceleration of processing speed was thought to be an important positive factor that influenced improvement of reading comprehension (e.g., Breznitz, 1997). This effect appeared in dyslexic as well as in normal readers but was more prominent in the dyslexic group. A possible explanation is that normal readers use their processing resources in the self-paced condition more effectively than dyslexic readers do. At the same time, increase of ERP amplitudes seemed to indicate more effort in the brain during processing at least of syntactic and morphological information.

It was previously suggested that the N100 corresponded to the search process by which the central points of sentences requiring focus of attention and more in-depth processing are identified (Leikin & Breznitz, 1999). Accordingly, the latencies’ decrease under the fast-paced condition may be interpreted as maximization of attention in reading because of a lowered susceptibility to distraction (Breznitz, 1997). In turn, P300 was explained (Leikin & Breznitz, 1999) as reflecting operations involving classification of target words and updating in short-term memory. The findings under the self-paced condition showed that the process of syntactic interpretation of the words seemed to be a more complex task for dyslexic readers than for normal readers (Breznitz & Leikin, 2000). This process might demand greater short-term memory resources. At the same time, under the fast-paced condition, decrease of ERP latencies was evinced together with improvement in comprehension. This finding confirmed Breznitz and Share’s (1992) data suggesting that improved working memory functioning because of an increase in the units available to et least partly determines the beneficial effects of reading-rate acceleration.

Thus, the results showed that accelerated reading rate influenced significantly processing of words playing different grammatical roles. On the one hand, it accelerated
the speed of processing in consequence of maximized attention and improvement of working memory functioning. On the other hand, faster reading rate caused more substantial effort in the brain during this processing. It may be suggested that the reason for such effort is a syntactic ‘weakness’ of dyslexic readers. It is characteristic that the modification of processing manner under the fast-paced condition was also followed by changes in the processing strategies.

It was previously shown (Leikin & Breznitz, 2001) that accelerated reading rate affected the processing mode and might change the patterns of processing in normal readers. An accelerated rate seemed to facilitate the processing of most of sentence elements. As a result, a distinct shift toward the word-order strategy was evident, along with preservation of the tendency to employ the verb-oriented pattern. However, acceleration of reading rate caused a more significant change in the processing mode in dyslexia, namely an evident shift toward the word-order strategy.

The patterns of brain activation descended characteristically in response to each of the studied sentence elements: subject > [predicate] > direct object > [modifier] > preposition. This pattern clearly reflected the SVO syntactic order. Accordingly, the positive effect of accelerated reading rate on sentence processing among dyslexic readers seemed to be realized by the passage from the defective verb-oriented strategy entirely to the word-order strategy. More effective usage of such a strategy also facilitated sentence processing.

CONCLUSION

The results seem to confirm the hypothesis (Leikin & Breznitz, 1999) that Hebrew readers use lexical-morphological properties of the words to identify their grammatical roles in the sentence. Still, the morphologically based strategy reaches full expression only in the presence of the verb, which in Hebrew sentences fulfills the central role.
Seemingly, readers dispose of several different procedures to identify words’ grammatical functions. Selection of a particular strategy may be influenced by different factors, including reading rate and lexical-morphological characteristics of the stimuli as well as level of reading skills.

The findings also demonstrated significant differences in sentence processing between normal and dyslexic readers. The dyslexic readers not only showed different brain activation patterns but also tended to use another strategy for identification of words’ grammatical functions: word-order strategy. This strategy seems less efficient for linguistic processing in Hebrew and represents a more primitive mode of identifying words’ syntactic functions. However, the word-order strategy seems to reflect the fundamental cognitive strategy of information processing, which is simpler in some situations. Dyslexic readers not only used it in the self-paced condition, but this strategy was also more effective in the case of accelerated reading rate for both groups of readers.

In addition, the findings corroborated the view of reading rate as the independent variable and previous data concerning the beneficial effect of accelerated reading rate on reading comprehension. The results confirmed the assumption that fast-paced reading rate might affect at least the first stage of syntactic parsing.

REFERENCES


Table 1. Mean results (and SDs) in ERP latencies and amplitudes (in Cz electrode) for three sentence elements in dyslexic (D) readers and controls (C)

<table>
<thead>
<tr>
<th>Measures</th>
<th>Subject</th>
<th></th>
<th>Predicate</th>
<th></th>
<th>Object</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>C</td>
<td>D</td>
<td>C</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>N100 Latency</td>
<td>120.9</td>
<td>114.3</td>
<td>116.9</td>
<td>108.1</td>
<td>119.3</td>
<td>106.5</td>
</tr>
<tr>
<td></td>
<td>(38.9)</td>
<td>(31.5)</td>
<td>(26.1)</td>
<td>(17.9)</td>
<td>(18.4)</td>
<td>(11.7)</td>
</tr>
<tr>
<td>N100 Amplitude</td>
<td>-6.4</td>
<td>-2.3</td>
<td>-4.0</td>
<td>-3.6</td>
<td>-4.1</td>
<td>-3.4</td>
</tr>
<tr>
<td></td>
<td>(1.7)</td>
<td>(1.9)</td>
<td>(3.6)</td>
<td>(1.9)</td>
<td>(3.0)</td>
<td>(1.9)</td>
</tr>
<tr>
<td>P200 Latency</td>
<td>325.0</td>
<td>281.6</td>
<td>289.4</td>
<td>241.3</td>
<td>279.3</td>
<td>249.3</td>
</tr>
<tr>
<td></td>
<td>(114.5)</td>
<td>(97.1)</td>
<td>(117.3)</td>
<td>(92.4)</td>
<td>(63.5)</td>
<td>(87.3)</td>
</tr>
<tr>
<td>P200 Amplitude</td>
<td>3.1</td>
<td>2.9</td>
<td>3.7</td>
<td>2.7</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>(2.3)</td>
<td>(1.0)</td>
<td>(2.6)</td>
<td>(1.2)</td>
<td>(2.9)</td>
<td>(1.7)</td>
</tr>
<tr>
<td>P300 Latency</td>
<td>411.7</td>
<td>405.6</td>
<td>392.6</td>
<td>380.3</td>
<td>435.5</td>
<td>366.5</td>
</tr>
<tr>
<td></td>
<td>(86.5)</td>
<td>(111.4)</td>
<td>(156.3)</td>
<td>(96.5)</td>
<td>(169.5)</td>
<td>(121.3)</td>
</tr>
<tr>
<td>P300 Amplitude</td>
<td>10.2</td>
<td>9.3</td>
<td>11.5</td>
<td>9.2</td>
<td>10.0</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>(6.3)</td>
<td>(4.7)</td>
<td>(6.5)</td>
<td>(3.7)</td>
<td>(4.2)</td>
<td>(2.7)</td>
</tr>
<tr>
<td>P600 Latency</td>
<td>807.4</td>
<td>727.6</td>
<td>791.0</td>
<td>682.3</td>
<td>865.3</td>
<td>692.4</td>
</tr>
<tr>
<td></td>
<td>(114.5)</td>
<td>(141.3)</td>
<td>(98.4)</td>
<td>(98.3)</td>
<td>(96.9)</td>
<td>(79.12)</td>
</tr>
<tr>
<td>P600 Amplitude</td>
<td>6.1</td>
<td>5.3</td>
<td>6.0</td>
<td>5.7</td>
<td>6.1</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>(4.1)</td>
<td>(3.7)</td>
<td>(3.9)</td>
<td>(4.0)</td>
<td>(4.3)</td>
<td>(3.9)</td>
</tr>
</tbody>
</table>
Table 2. Mean results and SDs of two groups of participants in behavioral baseline tasks

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Dyslexics</th>
<th>Controls</th>
<th>F (1,39)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Self-paced, full screen</td>
<td>11.5</td>
<td>2.6</td>
<td>15.1</td>
</tr>
<tr>
<td>comprehension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-paced, full screen</td>
<td>237.1</td>
<td>34.5</td>
<td>166.3</td>
</tr>
<tr>
<td>time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-paced, window screen</td>
<td>10.9</td>
<td>4.1</td>
<td>15.2</td>
</tr>
<tr>
<td>comprehension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-paced, window screen</td>
<td>288.5</td>
<td>44.6</td>
<td>189.7</td>
</tr>
<tr>
<td>time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast-paced, window screen</td>
<td>14.3</td>
<td>2.5</td>
<td>16.7</td>
</tr>
<tr>
<td>comprehension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast-paced, window screen</td>
<td>207.6</td>
<td>39.7</td>
<td>151.3</td>
</tr>
<tr>
<td>time</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

***p < .001
Table 3. Means (and SDs) for N100 amplitudes and latencies in self- (SPC) and fast-paced (FPC) reading conditions in the five sentence elements (Cz electrode)

<table>
<thead>
<tr>
<th>Sentence elements</th>
<th>Dyslexics</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitudes (in mV)</td>
<td>Latencies (in ms)</td>
</tr>
<tr>
<td>SPC: Subject</td>
<td>-2.54 (1.2)</td>
<td>117.1 (10.7)</td>
</tr>
<tr>
<td>FPC: Subject</td>
<td>4.2 (1.9)</td>
<td>71.4 (13.4)</td>
</tr>
<tr>
<td>SPC: Predicate</td>
<td>-6.0 (1.1)</td>
<td>100.2 (13.8)</td>
</tr>
<tr>
<td>FPC: Predicate</td>
<td>-7.8 (1.4)</td>
<td>86.0 (16.8)</td>
</tr>
<tr>
<td>SPC: Object</td>
<td>-2.0 (.6)</td>
<td>71.5 (9.1)</td>
</tr>
<tr>
<td>FPC: Object</td>
<td>1.7 (1.0)</td>
<td>65.1 (11.0)</td>
</tr>
<tr>
<td>SPC: Modifier</td>
<td>-2.4 (1.0)</td>
<td>75.1 (7.0)</td>
</tr>
<tr>
<td>FPC: Modifier</td>
<td>2.4 (1.3)</td>
<td>67.1 (8.0)</td>
</tr>
<tr>
<td>SPC: Preposition</td>
<td>-2.8 (1.7)</td>
<td>72.2 (11.9)</td>
</tr>
<tr>
<td>FPC: Preposition</td>
<td>2.7 (1.1)</td>
<td>69.0 (16.1)</td>
</tr>
</tbody>
</table>
Table 4. Means and SDs for P300 amplitudes and latencies in self- (SPC) and fast-paced (FPC) reading conditions in the five sentence elements (Cz electrode)

<table>
<thead>
<tr>
<th>Sentence elements</th>
<th>Dyslexics</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitudes (in mV)</td>
<td>Latencies (in ms)</td>
</tr>
<tr>
<td>SPC: Subject</td>
<td>2.5 (.8)</td>
<td>359.0 (39.6)</td>
</tr>
<tr>
<td>FPC: Subject</td>
<td>3.5 (1.1)</td>
<td>293.7 (23.1)</td>
</tr>
<tr>
<td>SPC: Predicate</td>
<td>3.2 (2.2)</td>
<td>396.3 (35.5)</td>
</tr>
<tr>
<td>FPC: Predicate</td>
<td>-4.1 (1.2)</td>
<td>329.8 (26.1)</td>
</tr>
<tr>
<td>SPC: Object</td>
<td>3.0 (1.4)</td>
<td>279.1 (22.6)</td>
</tr>
<tr>
<td>FPC: Object</td>
<td>2.5 (1.4)</td>
<td>316.8 (29.4)</td>
</tr>
<tr>
<td>SPC: Modifier</td>
<td>2.0 (1.9)</td>
<td>302.0 (39.6)</td>
</tr>
<tr>
<td>FPC: Modifier</td>
<td>3.7 (1.3)</td>
<td>310.2 (43.2)</td>
</tr>
<tr>
<td>SPC: Preposition</td>
<td>2.7 (1.3)</td>
<td>381.1 (20.9)</td>
</tr>
<tr>
<td>FPC: Preposition</td>
<td>2.8 (1.3)</td>
<td>285.4 (31.8)</td>
</tr>
</tbody>
</table>