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IDENTIFICATION OF GRAMMATICAL FUNCTIONS IN THREE LANGUAGES

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Abstract

The present study investigated brain activity (ERP) in trilingual (Arabic/Hebrew/English) readers when processing the grammatical functions of words while reading sentences in three languages. Twenty native Arabic-speaking university students participated in this study. Differences between syntactic processing strategies in Arabic, Hebrew and English, as first, second and third languages respectively, were investigated. P300, N400 and P600 ERP components were identified for three grammatical functions (subject, predicate and object) in each sentence, in all reading items, in all three languages. Analysis of the results showed that, in English, the participants used the word-order strategy, whereas in Hebrew, a mixed (word-order, verb-oriented, and morphology-based) strategy was used. The verb-oriented strategy was also used in Arabic. The findings suggest that the different processing strategies are influenced specifically by the language in which reading takes place and the morphological and grammatical properties of that language. Differences in localization patterns between the languages and the grammatical functions were also observed.

Keywords: Bilingualism, ERP, Syntactic processing, Grammatical functions, Arabic, Hebrew.

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1. Introduction

The present study addresses the syntactic processing of different grammatical functions in later trilinguals (after age 7), in their L1 (Arabic), L2 (Hebrew) and L3 (English) languages. We also investigate the influence of different language structures, in three different languages, on the choice of the specific strategy for identifying grammatical structures, and the associated brain activation underlying these processes.

1.1. Identification of the grammatical functions of words

The act of sentence comprehension requires, among other things, the processing of words in sentences such that words are assigned an immediate syntactic categorization, allowing attribution of their grammatical functions (e.g., subject and predicate). This, in turn, is used to construct a single preliminary phrase structure (Mitchel, 1987). The grammatical functions and syntactic structure of the sentence, as a whole, carry meanings of their own, which must be extracted by the reader when grasping the meaning of the sentence (Kako, 1999). Recent literature suggests that identification of the grammatical functions of words is made possible by reference to varied sources of information, such as word order, inflectional morphology, and the lexical-morphological properties of individual words (Clahsen & Felser, 2006; Ferstl & Flores d'Arcais, 1999; Hahne, Mueller & Clahsen, 2006). However, various sources of information appear to contribute differently to this process, in different languages. It has been suggested by Kempe & MacWhinney (1999) that the greater the availability of a cue, the larger the processing benefits associated with the presence of such a cue, and the smaller the effect of other converging information. In English, for example, the syntactic order of sentence components is usually fixed; hence, word order is highly important for sentence processing (Bates, Devescovi, D'Amico, 1999). The situation is different, however, when the syntactic structures are not necessarily in a fixed order, as is the case in Semitic languages such as Hebrew and Arabic (Leikin, 2002; Leikin & Ritvas, 2012).

In Hebrew and Arabic, derivational morphology is the most characteristic feature of the language (Deutsch, Frost, Pollatsek & Rayner, 2005), so that recognition of the lexical-morphological characteristics of words makes available important syntactic information (Leikin, 2002; Shalhoub-Awwad & Leikin, 2016; Shimron, & Sivan, 1994). Parsers may use "lemma information", i.e. detailed lexical-syntactic information, to achieve the syntactic categorization of words (Mitchel, 1987). For example, they may use information about argument structures in which different verbs take part in the thematic roles of syntactic arguments. The parser may attribute grammatical functions to words in sentences using the lexical entry of a word, together with other sources of information (Leikin, 2002, 2008). Several studies investigating the role of morphological units in the Arabic and Hebrew mental lexicon have suggested that verbs and nouns are organized differently (e.g., Frost & Grainger, 2000; Deutsch et al., 2005; Shalhoub-Awwad & Leikin, 2016). In particular, it was concluded that, while in the nominal system word patterns do not govern the process of the lexical system, within the verbal system, verbal-pattern morphemes play a role in lexical organization.

Several studies (Breznitz & Leikin, 2000, 2001; Leikin, 2002, 2008; Leikin & Breznitz, 1999, 2001; Leikin & Ritvas, 2012) used the ERP technique to examine the contribution of the grammatical

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functions of words and the identification of grammatical functions to sentence processing, among average Hebrew-speaking adult readers. Brain activity was examined during the processing of various parts of a sentence. The obtained effect pertained to the amplitudes and latencies of the N100/P200, P300, and P600 ERP components. This effect was manifested in the form of distinct differences between the three central parts of the sentence (subject, predicate, and object), with the largest differences observed for the predicate part. The findings suggest that changes in ERP amplitudes and latencies do not relate to ordinal word position and word-class differences between target words, but are associated with the words' grammatical functions. The effect was understood as an indication of the processes involved in the identification of the words' grammatical functions (Leikin, 2002). Hebrew-speaking readers, for instance, tended to utilize the predicate-oriented morphology-based strategy for processing the grammatical functions of words. This strategy was reflected in the descending order of the grammatical functions of words according to the level of their activation: predicate > subject > direct object ³ modifier; though this seems to be language-related and complicated, to a certain extent, even for native speakers of Hebrew (Leikin & Breznitz, 2001, Leikin, 2008; Leikin & Ritvas, 2012). Moreover, this strategy seems to develop at relatively later stages of language/reading acquisition (Sokolov, 1984), and Hebrew-speaking readers use several additional procedures for processing the grammatical functions of words, including the word-order strategy (Leikin, 2002). Selection of a particular strategy may be influenced by different factors, including the lexical-morphological characteristics of the stimuli.

Note, however, that the results obtained in Hebrew cannot be generalized, or even adequately interpreted, in the absence of data from other languages. For example, in contrast to Hebrew, native Russian speakers use morphology-based, noun-oriented strategies (Leikin & Ritvas, 2012), while in English, for the same purpose, readers use a word-order strategy (Leikin & Ritvas, 2012). The Arabic language has not been studied from this point of view; however it is known that Arabic and Hebrew are both Semitic, root-derived, synthetic languages which are characterized by rich and highly productive derivational and inflectional morphology (Abu-Rabia, Share, & Mansour, 2003; Shalhoub-Awwad & Leikin, 2016). Nonetheless, despite the fact that these languages seem similar in many respects, they are actually quite different (Eviatar, Ibrahim & Ganayim, 2004). These differences may be found in almost all of the language domains, e.g. phonology, orthography and/or morphology. Arabic appears to be more complex grammatically because word formation processes are thought to be more complicated in Arabic than in Hebrew, and because Arabic has many more irregularities compared with Hebrew (Buckwalter, 2004; Soudi, Van den Bosch & Neumann, 2007).

1.2. Bilingualism and morpho-syntactic processing

Another aspect of the problem has to do with cognitive and neurophysiologic characteristics of bilingual language processing. Several studies on language processing by bilinguals have used ERP measures. Investigation of semantic aspects of language processing found the latency of the N400 component for semantic anomalies to be delayed in fluent bilinguals, compared with monolinguals; and in L2 compared with L1 within the bilingual group (Alvarez, Holcomb & Grainger, 2003; Hahne et al., 2006; Weber-Fox & Neville, 1996). For phrase structure violations, monolinguals showed differential effects for an early left anterior negativity (N125) and a second left lateralized negativity (N300±500),

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which were followed by a P600 effect (Hahne et al., 2006; Weber-Fox & Neville, 1996). Late L2-learners displayed a more bilateral ERP pattern for syntax-related negativity (N300±500) and an absence of P600 modulation , which has been interpreted as reflecting a process of syntactic reanalysis and repair (Friederici, 2002). Other studies, however, detected P600 effects among L2 learners in the same conditions as among native speakers (e.g., Hahne & Friederici, 2001). Considered together, these results suggest that morpho-syntactic processing of L2 learners depends, among other things, on their language proficiency (Clahsen & Felser, 2006).

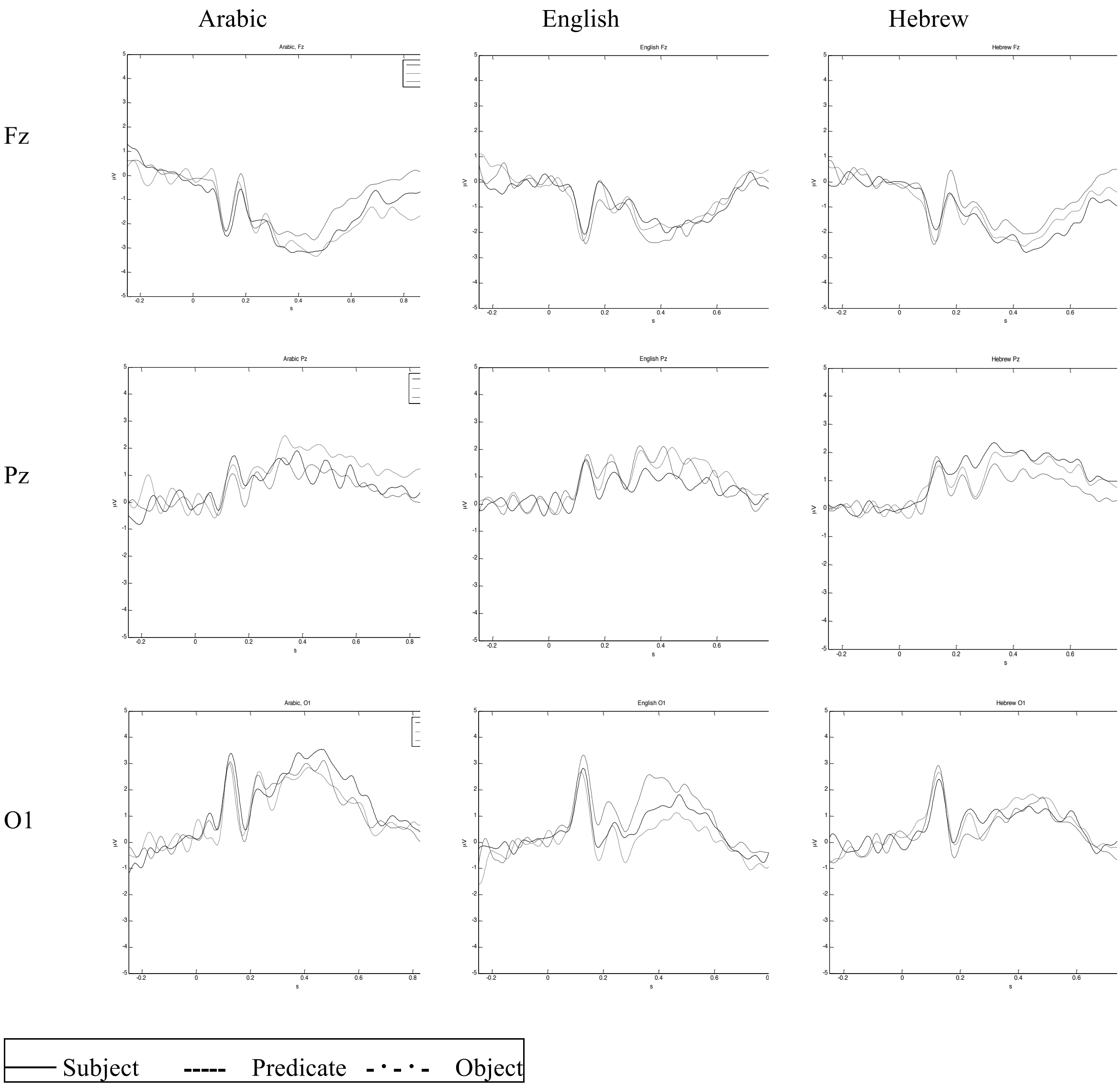

Figure 01. The most prominent ERP appeared in the Fz, Pz, O1 electrode

2. Problem Statement

The literature regarding processing of words' grammatical functions is limited. Only a few studies have used ERP measures to examine this type of processing by bilingual and trilingual parsers.

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Additionally, there are almost no studies that systematically compare Hebrew and Arabic languages as well as these Semitic languages and English language.

3. Research Questions

The study addressed the following questions:

1.What are differences between processing strategies and patterns of brain activation in different grammatical functions in Arabic as the first language (L1)?

2.Whether there are differences between processing of words' grammatical functions in L1 and L2/L3.

4. Purpose of the Study

The goal of this study was to examine brain activity through ERP amplitudes and latencies and areas of brain activation, in adult native Arabic speakers, when processing the grammatical functions of words during the reading of sentences in three languages: Arabic as L1, Hebrew as L2 and English as L2 andL3. Primarily, we proposed to investigate differences between processing strategies and patterns of brain activation in different grammatical functions in Arabic as the first language (L1). In addition, we intended to trace differences in ERP measures between processing patterns in the first, and then second / third languages.

We hypothesized that there are substantial differences between sentence processing in L1 and L2/L3. Specifically, we suggested that readers identify the grammatical functions of words using morphology-based verb-oriented strategies in Arabic and Hebrew, and word-order strategy in English. Furthermore, we anticipated that all the characteristics of native and second language processing outlined above would have clear neurophysiological correlates as manifested by changes in the amplitudes and latencies of N100/P200, P300, and P600 ERP components; with variation in the localization of brain activation for L1 and L2/L3 sentence processing.

5. Research Methods

Twenty native Arabic-speaking male university students at normal reading level participated in the study. All students were later trilinguals, and started acquiring Hebrew and English in their third and fourth grades at school, respectively. All of them were proficient trilinguals in all three languages, with high levels of reading ability and reading comprehension in these languages. The participants ranged in age from 20-27 years (M=22.1, SD=2.5), were right-handed and displayed normal or corrected-to-normal vision in both eyes. They did not report any history of having had reading disabilities or problematic neurological signs. All participants were paid volunteers.

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5.1. Electrophysiological Baseline Measures

Target detection tasks were administered in order to habituate the participants to the experimental situation and to verify correct response in terms of brain activity (P300 component). The tasks were administered in visual modalities. Stimuli were two Hebrew block letters (64. ,(ג ,ש cm (1/4 in.) high, presented successively at the center of a computer screen. Stimulus presentation time depended upon the latency of the participants' responses. Targets occurred 20% (n=20) of the time and non-targets 80% of the time (n=80). Stimuli were presented for a duration of 250 ms at an ISI of 700 ms. Participants were asked to count the target stimuli and ignore the non-targets.

Experimental Stimuli: 30 groups of sentences, each group consisting of 3 sentences (a total of 90 sentences). in each of the three languages (Arabic, Hebrew and English), were presented. The sentences consisted of 2-8 words. In each group, the same word appeared in the three different grammatical functions: predicate, subject and object. Only the Literary form of Arabic was used; this form indicates the syntactic function of the word by means of vowelization of its final letter. Some of the sentences were followed by a statement relating to the previous sentence, and the participant had to indicate whether or not the sentence is correct. In English and Hebrew, these were regular declarative sentences in SVO (subject-verb-object) syntactic order. In Arabic, however, the word order was different: verb-subject-object. The target word appeared at the beginning of the sentence, as subject; or in the intermediate or terminal position, as predicate; or in the intermediate or terminal position, as object. For example, in English: "The blue car crossed the northern crossroad. A little boy broke the toy car. The strange object was an old car". The same sentences (from the semantic point of view) were used in Hebrew and Arabic. In Hebrew:

המכונית הכחולה חצתה את הצומת הצפוני. ילד קטן שבר את מכונית הצעצוע. האובייקט המוזר היה מכונית ישנה.

In Arabic:

قطعت السيّارة ُ الزرقاءُ المفترقَ الشماليَّ. كسّر طفلٌ صغيرٌ سيارّة َ اللعبِ. كان الغرضُ الغريبُ سيّارة ً قديمة ً.

The words were selected on the basis of similar frequencies in Hebrew, English and Arabic, as well as their length. In order to avoid the repetition effect, phonologically similar words in Hebrew and Arabic were replaced, in Arabic, by other words, trying not to significantly change the meaning of the sentence. For example, the word "apples", that sounds similar in both languages ("tapuhim" and "tufah"), was changed in Arabic to "orange" ("burtukal"). The participants read all of the sentences in the three languages.

Procedure: Each testing session lasted approximately 60 minutes. Participants were seated in a quiet room, 1.5 meters from a PC (Windows) computer screen. Experimental task presentation was counterbalanced. Participants were connected to an Electro-cap and were instructed to remain quiet and refrain from moving during the testing session. They were also told that it was important to avoid excessive eye movements and blinking as much as possible.

The items appeared one at a time on the computer screen. Participants were instructed to begin reading the item the moment it appeared on the screen. After reading the item, they pressed a button on the keyboard, whereupon the text was automatically erased and the multiple-choice questions were displayed. Participants indicated their answer by pressing a number on the keyboard (1-4) that corresponded to the answer chosen. Measures of comprehension and reaction times were determined for

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each reading item in the two presentation conditions. The two forms were counterbalanced across one experimental condition.

5.2. Window presentation (with electrophysiological measures)

The stimulus sentences appeared word by word. This manner of presentation was adopted so as to reduce eye movements by focusing the participant's gaze on the center of the computer screen. Since word presentation rates were individually calculated for each reader, presentation rates differed across participants.

Thirty-two channels of electroencephalogram (EEG) activity were recorded using a Bio-Logic Brain Atlas III computer system with brain mapping capabilities. The system used a bandpass of 0.1-70 Hz interfaced with a 20-channel, 12-bit A/D converter. The EEGs were sampled at a rate of 250 Hz (dwell time = 4.0 ms), beginning at 100 ms before stimulus onset. The full array of electrodes was positioned according to the International 10/20 system (Jasper, 1958) by means of an Electro-cap (a nylon cap fitted over the head with 9 mm tin electrodes sewn into it). Nineteen scalp electrodes were used, according to standard 10/20 system locations: PF1, PF2, F7, F3, FZ, F4, F8, T3, C3, CZ, C4, T4, T5, P300, PZ, P4, T6, O1, O2, all 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 movement. During data collection, electrode impedances were kept below 5K by first treating scalp areas with a mildly abrasive cleanser (Omni-Prep) and using an electrolyte gel (Electro-gel). Trial onset was marked on the Oz channel of EEG by a positive polarity 5 millivolt pulse delivered from an IBM-PC 486 computer. The pulse was delivered at the beginning of each word in each item. Signal averaging of the raw EEG data was performed off-line.

EEG data were separated into discrete trials. After the eye-movement correction, we determined the averages of the individual trials according to the experimental data set. There were three average trials, one for each of the three sentence elements across items (separately for each language). The averages were combined to form one set per participant, resulting in one data set for each participant, and reflecting averaged EEG activity of the words representing subject, predicate, and object in two of the three languages; and for first and second language conditions. Evoked potentials were measured for each participant, for each word, in every item. Only single trials free from eye movements and associated with correct responses were averaged to obtain the event-related potentials. Grand averages over conditions and subjects were then performed for each experiment, for each of the 19 scalp electrodes. ERP peaks were first identified and then validated by a machine-scoring algorithm. Latencies were measured from stimulus onset. Amplitudes were measured relative to the mean voltage of each channel during the pre-stimulus baseline.

6. Findings

In all participants, P300, N400, and P600 ERP waves were identified for subject, predicate, and object in each sentence, in all reading items, and in all three languages. Baseline adjustment was performed according to the average values, which were measured in the interval between 200 ms and

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stimulus appearance, for each separate grammatical function. The most prominent ERP appeared in the Fz, Pz, O1 electrode (Fig.1).

Mixed factorial ANOVAs were performed to compare brain activity among participants when reading sentences in Arabic, Hebrew and English. ANOVAs were performed on amplitudes and latencies of P300, N400 and P600 ERP components (a total of 12 ANOVAs). Language, grammatical function and scalp region served as within-subject factors in these analyses. In all ANOVAs, Greenhouse-Geisser correction was applied for sphericity values lower than 0.75, and Huynh-Feldt correction was applied for sphericity values greater than 0.75 (Field, 2005). In order to control the overall probability of Type I errors, a corrected significance better than 1-0.951/12≈0.0043 was required in these ANOVAs.

The following significant effects occurred in the comparison of brain activity while reading in three different languages:

1. A main effect of language on the amplitudes of the following components was found: P300 ($F_{1.88,24.40}$=10.04, p<0.01), N4 00($F_{1.58,20.57}$=10.03, p<0.01), P600 ($F_{2,26}$=9.79, p<0.01). The amplitudes were higher)more positive(in Hebrew sentences than in English ones, and they were higher in English than in Arabic. A similar effect was found in Leikin (2008) and Leikin and Ritvas (2012) studies, which investigated syntactic processing in Hebrew, English and Russian languages by native and bilingual adult readers. It was shown that processing in Hebrew elicited higher amplitudes compared to English and Russian, among native and non-native Hebrew speakers. A similar effect concerning English as a second language was also found previously in the research of Breznitz, Oron and Shaul (2004). In that study, a higher amplitude for English as a second language was evident among regular and dyslexic native Hebrew speakers, and was explained by greater effort needed for processing a second language (Breznitz et al., 2004). Additionally, differences in the processing of the different languages must be taken into account.

2. A main effect of grammatical function on the amplitudes of the P600 component was found: $F_{2,26}$=8.52, p<0.0. The amplitudes were more positive while processing the predicate than while processing the object, and while processing the object than while processing the subject. These results are in line with our previous findings demonstrating the processing of the grammatical functions of words during syntactic parsing of the sentence (Leikin & Breznitz, 1999: Leikin, 2002).

3. A main effect of region on amplitudes of the following components was found: P300 ($F_{1.62,21.08}$=15.14, p<0.001), N400 ($F_{1.58,20.50}$=19.88, p<0.001), P600 ($F_{1.55,20.09}$=16.40, p<0.001). The amplitudes were higher in the posterior areas of the brain than in the central areas, and in the central areas the amplitudes were higher than in the anterior areas. The same pattern of brain activity was observed in a previous study by Leikin and Ritvas (2012), which investigated grammatical functions in Hebrew, English and Russian. This effect was interpreted as a manifestation of greater involvement of posterior brain regions in language processing (including morphological processing).

4. A language x grammatical function interaction on amplitudes of P300 ($F_{3.11,40.42}$=5.35, p<0.01) and N400 ($F_{3.17,41.21}$=4.97, p<0.01) components were found.

In Hebrew, in the P300 component, the subject and predicate elicited the same amplitude, while the object elicited a much lower amplitude. However, in the N400 component, the following pattern of

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activity was observed: predicate>subject>object. A similar pattern was observed in a previous study (Leikin & Breznitz, 1999), where the predicate also received the greatest activation.

For English, the following pattern was observed for both P300 and N400 components: object>predicate>subject. In a previous study (Leikin 2008), this pattern was identified for reading in English among native Hebrew speakers and was interpreted as indication of a word- order strategy (Leikin, 2008).

For Arabic, the following pattern of amplitudes was observed, also for both components (P300 and N400): predicate> object> subject.

Figures 2 and 3 demonstrate the significant differences in P300 and N400 amplitudes obtained for the processing of the three grammatical functions (subject, predicate and object) in the three different languages (Arabic, Hebrew and English).

6.1. Analysis of the sources of activity

In order to describe the experimental conditions and timings in which differences in the sources of brain activity were observed, comparisons of scalp maps were performed (TANOVA - Strik, Fallgatter, Brandeis, & Pascual-Marqui, 1998) using the LORETA-Key computer program (Low Resolution Electromagnetic Tomography). Topographies were compared between languages (Arabic, English and Hebrew) for each grammatical role (subject, predicate object), and between grammatical roles in each language (a total of 18 comparisons). In order to control the overall probability of Type I errors, a corrected significance better than 1-0.951/18≈0.0028 was required in these comparisons. Analysis revealed several significant differences as follows:

I. A difference in processing different grammatical functions in the Arabic language: A greater activation during the processing of subjects versus predicates was found at 469-504 ms after stimulus onset, which supposedly is an early representation of the P600 ERP component. This component is associated with controlled processes of syntactic reanalysis and repair (Friederici et al., 1996; Hahne & Friederici, 1999), and is thought to reflect the effort to distinguish between the different grammatical roles of words in sentences. The differences were evident in the Left Superior Temporal Gyrus, which is believed to detect and recognize elements of language (Breznitz et al., 2004) and is associated with processing semantic violations (Friederici, Kotz, Werheid, Hein et al., 2003). Possibly, the activation for the subject is greater in this area, since the subject conveys more semantic information than the predicate. The same pattern of activation was also found in the Anterior Cingulate Cortex (ACC), which was found to be involved in the processing of complex competing linguistic stimuli, and is also a part of the cortical attentional circuit (Rota, Veit, Nardo, Weiskopf, et al., 2008). The ACC is also related to executive and cognitive control (Bush, Luu, & Posner, 2000), which is closely linked to language control (Miller & Cohen, 2001). Most notably, the ACC may act as a sensor of cognitive conflict (Botvinick, Nystrom, Carter, et al., 1999; Botvinick, Braver, Barch, Carter, et al, 2001). Conflict during language switching among bilinguals may arise when leaving a strong language system and entering a relatively weak system, i.e. the lessexposed-to language (Abutalebi, Brambati, Annoni, Moro et al., 2007), or when bilinguals face potential language interference (Price, Green, & von Studnitz, 1999; Wang, Xue, Chen, Xue et al., 2007). This suggests that switching into a less exposed-to language requires controlled

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processing resources (Abutalebi et al., 2007). It is possible, therefore, that participants engaged in active language control, because they had to constantly switch back and forth among the three languages during the experiment.

In addition, activation was also evident in the Left Supramarginal Gyrus, which was found to be involved in the reanalysis of syntactic information and the unification of this information to compute the meaning of the sentence. The activation of this region seems to indicate that the participants performed the syntactic analysis of the sentences in order to grasp their meanings, and so had to distinguish between the subjects and the predicates in the sentences.

II. At 535-641 ms after stimulus onset, a greater activation during the processing of subjects versus predicates in the Arabic language was found. This reflects the P600 component, associated with controlled processes of syntactic reanalysis and repair (Friederici et al., 1996; Hahne & Friederici, 1999). The activation was found in three brain regions: a) the Left Supramarginal Gyrus, which was found to be involved in the reanalysis of syntactic information and the unification of this information to compute the meaning of the sentence (Bahlmann, Rodriguez-Fornells, Rotte,M. & Munte, 2007), and which is identical to the role of the P600 component; b) the Left Postcentral Gyrus, a somatosensory region (Maravilla, Richards, Berninger, Winn, et al., 2007) whose activation is associated with semantic processing (Borowsky, Esopenko, Cummine, & Sarty, 2007) and may reflect the semantic processing of the words; and c) the Left Precuneus, which is a part of an episodic memory network (Fernandes, Davidson, Glisky, & Moscovitch, 2004). It was suggested that activation in the Precuneus represents reactivation of stored engrams (Roland & Gulyas, 1995) and of stored memories of words (Fernandes et al., 2004). It seems that this activation may represent the activation of memories of the words, all of which were familiar to the participants. Again, Left Hemispheric activation was especially evident, consistent with previous findings concerning reading in the native language which showed that late proficient bilinguals exhibit LH dominance for their first language (Hull & Vaid, 2006).

III. A difference between processing subjects in Arabic and in Hebrew was found: A greater activation while processing subjects in Arabic was observed at 113-160 ms after stimulus onset, which represents the P200 component associated with late sensory and early perceptual processes, and is also sensitive to different grammatical classes (Pulvermuller, Preissl, Lutzenberger, & Birbaumer, 1996). Differences were found in the following brain regions: a) the Right Middle Temporal Gyrus, found to be active in several studies addressing syntactic processing (Indefrey, 2004) and during semantic comprehension of written material (Simos et al., 1997); thus it reflects semantic and syntactic processing; b) the Right Insula showed the same activation pattern, and it has previously been involved in sentence processing (Kircher, Brammer, Tous, Williams, & McGuire, 2001) and syntax processing (Gernsbacher & Kaschak, 2003; Kaan & Swaab, 2002); c) the Cingulate Gyrus, which has previously been associated with greater attentional demands in a silent word recognition task (Li, Cheung, Gao, Lee et al., 2006) was activated; and finally, d) activation was evident in the Right Superior Temporal Gyrus, which is associated with processing semantic violations (Friederici et al., 2003). The regions activated indicate visual and attentional demands required by the task, as well as semantic and syntactic processing. The greater Right Hemispheric activation is in line with previous findings which suggest that the representation of grammatical aspects of languages seems to differ between the two languages, if L2 is

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acquired after age 7 (Neville et al., 1992, 1997; Weber-Fox & Neville, 1997; Kim, Relkin, Lee, & Hirsch, 1997); which is indeed the case in this experiment.

IV. A greater activation during the processing of subjects in Arabic compared to Hebrew was found at 266-273ms, 309-336ms and 645-797ms after stimulus onset, which reflects a similarity to the P300 and P600 ERP components. The differences occurred in the Right Inferior Frontal Gyrus, which is associated with semantic processing (Dapretto & Bookheimer, 1999).

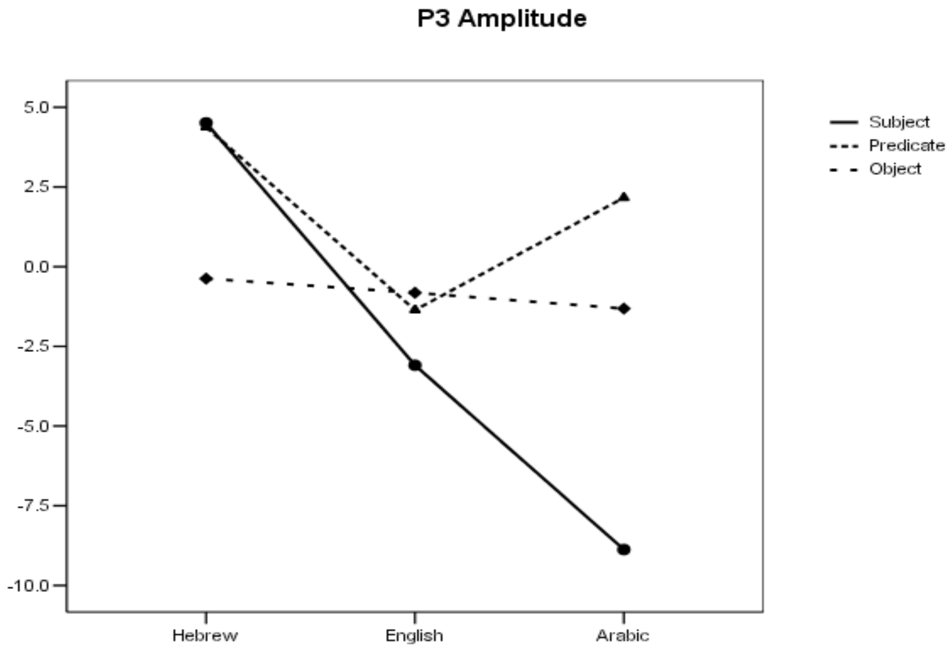

Figure 02. Language x grammatical function interaction on P3 amplitude

7. Conclusion

The first hypothesis concerned differences in processing between the three different languages (Arabic, Hebrew and English). Said differences were in fact found, in the form of amplitude differences in the P300, N400 and P600 ERP components. These components are associated with semantic, morphological, and, partly, syntactic processing (Kutas & Van Petten, 1994; Friederici, 2002). The amplitudes were higher)more positive(in Hebrew sentences than in English sentences, and they were higher)more positive(in English sentences than in Arabic sentences. A similar effect was shown in our previous studies (Leikin, 2008; Leikin & Ritvas, 2012). Stronger activation in Hebrew may be due to specific properties of Hebrew, like its rich derivational morphology, which require a greater effort for processing. Note also that this finding is consistent among native and non-native Hebrew speakers with different mother tongues (Leikin, 2008; Leikin & Ritvas, 2012). Accordingly, higher amplitudes in English compared to Arabic might reflect a greater effort in processing sentences in a second language (English), as it requires more brain effort than processing the first (Arabic) language. Similar findings were obtained in a previous study (Breznitz et al., 2004), which showed higher amplitudes for reading in English among native Hebrew speakers.

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The hypothesis regarding the existing differences between strategies of sentence processing in the three different languages was also supported. It was proposed that sentences in English would be processed differently than in the two Semitic languages, and this hypothesis was indeed confirmed. Differences in amplitudes of the N400 and P300 ERP components were found to be a result of processing different grammatical functions in the three different languages. Changes in these components were associated with processes contributing to the first stage of semantic parsing (Mitchel, 1994); that is, they seemed to be sensitive to processes of identification and analysis of the target words in accordance with their grammatical role (Leikin & Breznitz 2001), and are also associated with semantic and syntactic processing (Hahne & Friederici, 2002; Kutas & Federmeier, 2000). Specifically in English, the pattern of amplitudes was as follows: object>predicate>subject, which confirms previous findings indicating that word order is the determinant of syntactic processing in English (Bates et al., 1999, Leikin, 2008). In English, the syntactic order of the sentence components is usually fixed, so word order is highly important for sentence processing (Bates et al., 1999); the subject is usually the first word in the sentence, and so its analysis is easier than the analysis of the last word in the sentence, which is the object. This pattern of activation is significantly different from the activation pattern found during processing of the same grammatical functions in Hebrew and Arabic. In Hebrew, in the P300, the subject and predicate elicited the same amplitude, while the object elicited a much lower amplitude. However, in the N400 component, the following pattern of activity was observed: predicate>subject>object, as previously found in Leikin and Breznitz (1999). As can be seen with Hebrew, a mixed strategy was observed, which might be the result of the specific kinds of sentences which were presented. It appears that Hebrew speakers tend to use the predicate-oriented strategy in sentence processing, even when the predicate is a noun. Nonetheless, this exact property of the sentence (noun as a predicate) is confusing, and elicits the need for the word-order strategy as well; and that is probably why both predicate and subject reach similar activation levels.

In addition, we examined the hypothesis concerning the similarities between Hebrew and Arabic, both being Semitic languages; it was confirmed only partly. In Arabic, the following pattern of activation was evident (P300 and N400): predicate>object>subject. Similar to Hebrew, in Arabic the predicate elicited most activation, which indicates its significance in sentence processing and suggests that the predicate-oriented strategy is used even when the predicates are nouns. This activation pattern in Arabic also reflects the sentence structure of Literary Arabic, in which sentences are built in the following order: verb, subject, object (Saiegh-Haddad, 2003). Even in the absence of a verb, Arabic speakers tend to search for one, or its replacement, which is reflected in seeing the greatest activation on the predicate. This basic predicate-oriented strategy is similar for Hebrew and Arabic, but it seems to be stronger in Arabic. As to the localization results, differences in processing different grammatical functions within the same language were found in the different activation levels of several brain regions. The results are in line with previous findings linking different grammatical functions to different brain regions (e.g., Hahne & Friederici, 1999). In addition, differences in processing the same grammatical functions in different languages were found; specifically, differences between the mother tongue (Arabic) and the second (Hebrew) and third (English) languages. Previous research has also found differences in processing the same grammatical functions between the native and second languages (e.g. Leikin, 2008). These results

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are consistent with previous findings suggesting that the representation of grammatical aspects of languages seems to be different between the first and second languages, if L2 is acquired after the age of 7 (Neville et al., 1992, 1997; Weber-Fox & Neville, 1997; Kim et al., 1997).

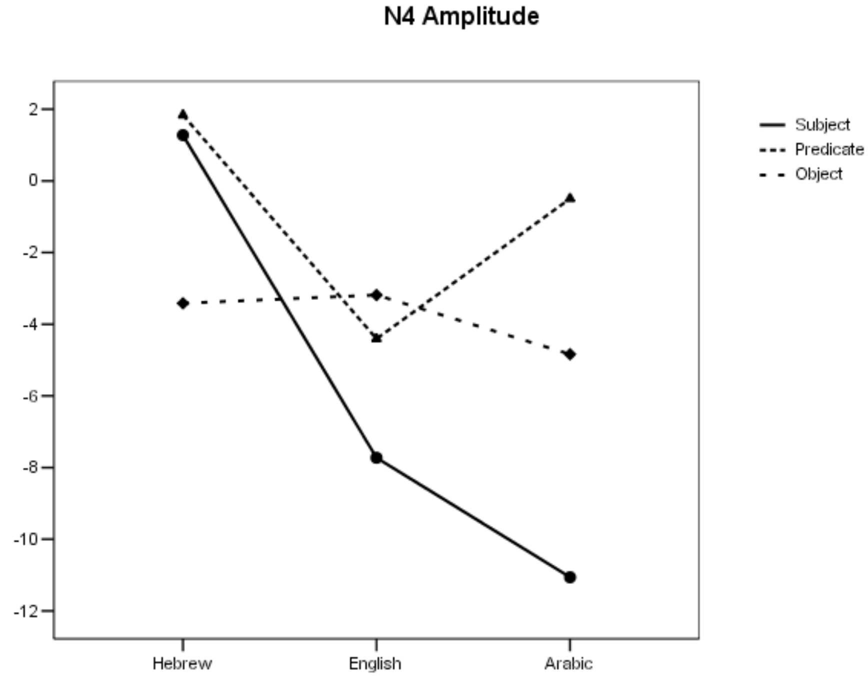

Figure 03. Language x grammatical function interaction on N4 amplitude

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