Published in final edited form as:

Int J Psychophysiol. 2011 December ; 82(3): 207–216. doi:10.1016/j.ijpsycho.2011.06.010.

Neurophysiology of Hungarian subject–verb dependencies with varying intervening complexity

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Abstract

Non-adjacent dependencies are thought to be more costly to process than sentences wherein dependents immediately follow or precede what they depend on. In English locality effects have been revealed, while in languages with rich case marking (German and Hindi) sentence final structures show anti-locality-effects. The motivation of the current study is to test whether locality effects can be directly applied to a typologically different language than those investigated so far. Hungarian is a “topic prominent” language; it permits a variation of possible word sequencing for semantic reasons, including SVO word order. Hungarian also has a rich morphological system (e.g., rich case system) and postpositions to indicate grammatical functions. In the present ERP study, Hungarian subject–verb dependencies were compared by manipulating the mismatch of number agreement between the sentence's initial noun phrase and the sentence's final intransitive verb as well as the complexity of the intervening sentence material, interrupting the dependencies. Possible lexical class and frequency or cloze-probability effects for the first two words of the intervening sentence material were revealed when used separate baseline for each word, while at the third word of the intervening material as well as at the main verb ERPs were not modulated by complexity but at the verb ERPs were enhanced by grammaticality. Ungrammatical sentences enlarged the amplitude of both LAN and P600 components at the main verb. These results are in line with studies suggesting that the retrieval of the first element of a dependency is not influenced by distance from the second element, as the first element is directly accessible when needed for integration (e.g., McElree, 2000).

Keywords

ERP (Event-Related Potentials); Locality effect; Anti-locality effect; Anterior Negativity (LAN); P600; Nonadjacent dependency; Sentence comprehension

1. Introduction

Two cohesive elements of a syntactic structure (e.g., subject and verb) are oftentimes separated by other words, such as in the sentence “The man who has a big black dog is swimming.” Although “the man” is the subject of the sentence, the second noun “dog” is closer to the verb “is swimming”, English-speakers would know that “the man” is swimming, not the “dog”. According to the “locality view” when a ‘dependent’ and what it depends on are divided by other discourse referents, it is more effortful for the comprehender to reactivate the first element for integration once the second element is available in the sentence (Gibson, 1998). Supporting the assumption of distance-based integration difficulties (Gibson, 2000), a self-paced reading study showed longer reading times for sentences with longer distance between constituents (Grodner and Gibson, 2005).

In contrast, some studies suggest that intervening sentence material within dependencies can decrease processing latencies (anti-locality effects) (Konieczny, 2000; Vasishth and Lewis, 2006). For example, Konieczny (2000) reported shorter reading times for longer argument-head distance as compared to when they were adjacent in German verb-final structures. The reason why the longer argument-verb distance can speed up processing is that the intervening words are able to facilitate the anticipation of the verb (Konieczny, 2000).

Locality effects are compatible with a “short-term storage buffer” view of WM, whereas other proposals put forward the idea that WM is not functionally distinct from long-term memory, but rather, instantiates an activation portion of it (e.g., Cowan, 1999). Converging evidence of this latter view is found with computational modeling (MacDonald and Christiansen, 2002), neurophysiological (Ruchkin et al., 2003), and behavioral data (e.g., Kessler and Meiran, 2010). Offering an alternative to the locality view, a number of studies have reported that distance between constituents worsens accuracy when judging the acceptability of sentences but does not increase processing latency (e.g., McElree, 2000; McElree et al., 2003). Specifically, this approach suggests that when the second element of a nonadjacent dependency is encountered, representation of the first element is retrieved by a direct-access operation (e.g., McElree et al., 2003). Moreover, instead of locality, similarity-based interference is taken to underlie more difficult processing of certain sentences (e.g., Van Dyke and McElree, 2006).

The distinction between the Dependency Locality Theory, (DLT) (Gibson, 2000) and the content-addressable memory account (McElree, 2000) pertains to different views of memory processes subserving sentence comprehension. According to the DLT (Gibson, 2000) there are restricted amount of memory resources available during sentence processing. Therefore, when two elements in a sentence are separated by new referents, it becomes more difficult to reactivate the first element for integration. On the contrary, from the standpoint of the content-addressable approach, the memory representation of the first element of a nonadjacent dependency can be directly accessed when the second element is available in the sentence (e.g., McElree et al, 2003). Furthermore, some argue that language processing relies on probabilistic information (e.g., Seidenberg and MacDonald, 1990; Jurafsky, 2003) and is incremental in nature (e.g., Rayner and Clifton, 2009; Konieczny, 2000). Furthermore, language elements can be anticipated by the previously encountered words (e.g., Konieczny, 2000), where predictions are based on statistical probabilities (e.g., Jurafsky, 2003).

The goal of the current study was to shed light on the locality vs. anti-locality issue by focusing on the processing characteristics of syntactic dependencies in Hungarian.

Hungarian is a topic-prominent, case-marking language; (É-Kiss, 1995) depending on the semantic context, different word orders are permitted such as Subject–Verb–Object (SVO)

and Subject-Object-Verb, (SOV) (É-Kiss, 2002; Puskas, 2000) as well as Object-Verb-Subject (OVS) word-orders in case the object is the topic of the sentence (Kálmán, 1985). Testing Hungarian dependencies can provide insight into the locality/anti-locality debate; because anti-locality effects have been found for verb-final structures with rich case morphology, such as in German and Hindi, whereas locality effects have been observed in SVO languages, such as English.

Neurophysiological recordings of non-adjacent dependencies report a focal negative brain potential occurring 300–500 ms post stimulus onset that is called the “Left Anterior Negativity” or LAN (see Vos et al., 2001, for a comprehensive review of LAN), and a positive potential occurring 500–800 ms post-stimulus onset, called the P600 component (see Kaan, 2002). Furthermore, in some cases, a Sustained Anterior Negativity (SAN) spanning over multiple words between the dislocated dependencies was also observed (e.g., Fiebach et al., 2002; King and Kutas, 1995; Phillips et al., 2005) and interpreted as the maintenance of the first dependency in WM until the integration can take place (e.g., Fiebach et al., 2002).

The focal LAN has been linked to constructing and holding online the first element, or reactivating it from WM, when encountering the second element of the dependency (e.g., King and Kutas, 1995; Kluender and Kutas, 1993), whereas P600 is thought to index integration difficulty of uncoupled syntactic dependencies (Fiebach et al., 2002; Kaan et al., 2000; Phillips et al., 2005). LAN and P600 have also been reported in studies solely focusing on grammatical violations without manipulating the distance between dependents (see Friederici, 2002; Hagoort, 2003). Furthermore, P600 has been observed in studies that did not employ syntactic violations but rather involve semantic manipulations (e.g., Kuperberg et al., 2003; Kolk et al., 2003; Hoeks et al., 2004; Kim and Osterhout, 2005).

ERP evidence for the locality view in previous studies were demonstrated as more negative amplitude of LAN (e.g., King and Kutas, 1995; Martin-Loeches et al., 2005) or SAN (Fiebach et al., 2002) or the enhancement of P600 components (e.g., Münte et al., 1997; Kaan et al., 2000) for the longer dependencies. In contrast, some studies reported that ERPs elicited by ungrammatical structures were not enhanced by integration distance and/or the complexity of the sentence. Specifically, smaller P600 amplitude (Gunter et al., 1997) or no effect on LAN (e.g., Gunter et al., 1997; Kaan, 2002) or P600 (e.g., Kaan, 2002; Vos et al., 2001) were found for longer distance and/or more complex structures.

In the current study, a mixed design paradigm, combining memory load and number mismatch between the subject and the verb, was used by exploiting the characteristics of the Hungarian language to examine non-adjacent dependency processing. This was done by manipulating the complexity of the intervening sentence material and morphosyntactic mismatch between the subject and the verb. Instead of comparing sentences of different lengths, (e.g., Martin-Loeches et al., 2005 or Phillips et al., 2005) distance was defined by the number of new discourse referents (Gibson, 2000) in the current study.

The main purpose of the current study was to test whether locality effects can be revealed in Hungarian. Integration is predicted to be more difficult at the verb if the distance between the verb and its dependents is increased (Gibson, 2000). By contrast, studies revealing anti-locality effects (e.g., Vasishth and Lewis, 2006) advocate that integration difficulty decreases with longer distance between dependents because of the reduction in uncertainty about the possible upcoming language elements.

Thus, the locality view predicts that complex structures will enlarge LAN and P600 as compared to simple sentences at the main verb. In contrast, the anti-locality assumption predicts that distance between constituents will not make sentence processing more difficult,

therefore no enhancement of LAN and P600 due to complexity manipulation is predicted at the main verb.

The complexity manipulation varied the intervening three-word sentence material between the subject and the verb. ERPs elicited by this region of the sentence is also of interest in the current study, considering that in previous studies the separating sentence material within dislocated dependencies elicited a SAN (e.g., Fiebach et al., 2002) spanning over the sentence material between the dislocated dependencies. The intervening three-word structures dividing the subject–verb dependency that were analyzed were a prepositional phrase in the simple condition (“a sötét üres szobában” ‘the dark empty room-INE’), and an intervening relative clause in the complex condition (“akié a pöttyös sál” ‘whose the dotted scarf (is)’). The intervening sentence material was analyzed in a single word comparison, using separate baseline for each word, because the multiple word epoch indicated more local differences based on visual inspection of the data (see Fig. A in the Appendix). The single word, non-cumulative comparison is in line with previous studies suggesting that the single-word comparison provides a more accurate analysis of the specific contribution of each word, than multiword ERPs with one common baseline (King and Kutas, 1995; Phillips et al., 2005).

2. Methods

2.1. Participants

17 native-Hungarian subjects (4 males, 19–27 years old, $M = 21$ years) participated in the study. Subjects were paid for their participation. All subjects had normal or corrected-to-normal vision and were right-handed, according to Annett's (1970) Handedness Questionnaire. Data from three subjects were eliminated from the final analysis due to excessive movement artifacts. None had a history of reading disorder, nor a history of neurological or psychiatric disorders.

3. Materials

The stimuli consisted of a list of 400 visually presented Hungarian sentences. Of these sentences 320 were the test sentences for the experiment. The remaining 80 sentences were fillers, which had similar sentence structures to decrease the participants' expectations for the critical manipulations. The filler sentences used all possible combinations (40 sentences had a plural head noun, and singular verb. In another 40 sentences the main verbs were plural and the head nouns were singular). Half of the filler sentences were simple and the other half were complex. All sentences contained five words, in which the first word was always a noun, and the last one was always an intransitive verb. One half of the sentences had a simple syntactic structure (simple condition), with a prepositional phrase between the subject and the verb. The remaining sentences were complex (complex condition), containing an embedded clause in between the subject and the verb. In addition to complexity, grammaticality was also manipulated. Half of the critical sentences were Grammatical (subject–verb agreed in number) and the other half Ungrammatical (subject–verb number mismatch). Table 1 presents examples of the sentences in the different conditions. 80 of the critical sentences were simple grammatical; 80 were simple ungrammatical; 80 were complex grammatical; and 80 were complex ungrammatical. The grammatical violation involved the mismatch of verbal agreement of number between the sentence's initial noun and the sentence's final intransitive verb. In all test sentences, the verb form was singular and half of the test material contained a plural subject (incorrect sentences) and half of them had singular subject (correct sentences), as in the following examples:

Correct sentence: A katona a sötét üres szobában ül./‘The soldier the dark empty room-INE sits’.

Ungrammatical sentence: A katonák a sötét üres szobában ül./‘The soldiers the dark empty room-INE sits’.

Fig. B in the Appendix shows ERPs elicited by the sentence initial nouns. ERPs indicated no differences between singular and plural subjects based on the visual inspection of the data. Additionally, ERPs evoked by the final verb of the sentences were examined and compared.

Another condition manipulated the distance of subject–verb intra-sentential dependency. The subject–verb dependency (“A katona ül”/‘The soldier sits’) was decoupled by an intervening prepositional phrase (“a sötét üres szobában”/‘the dark empty room-INE’) or by an intervening clause (“akié a pöttyös sál”/‘whose the dotted scarf (is)’). In Hungarian, the relative pronoun *akié* (third person singular anaphoric possessive in the nominative) must agree with the head noun in number, therefore, in the complex ungrammatical condition, where the head noun was plural, the pronoun agreed with it as in the following example:

A katonák, akiké a pöttyös sál ‘The soldiers whose[PL] the dotted scarf (is)’

ERPs elicited by the sentence material intervening between the subject and the verb were also compared in the different conditions.

3.1. Procedure

All subjects were presented with a list of sentences, containing all four conditions (*Simple Grammatical*, *Simple Ungrammatical*, *Complex Grammatical*, *Complex Ungrammatical*), plus the filler sentences in random order, for a total of 10 blocks (40 sentences each). Sentences were presented one word at a time. Each word appeared on the screen for 400 ms, and ITI was also 400 ms. In 30% of the total 400 sentences, two types of test questions (in 15%–15% of the total sentences) were asked, in a random manner, to keep the subject focused. After the last word of the sentence, a blank screen was presented for 800 ms. Then in 30% of the total sentences (including fillers) a test question appeared on the screen until responding. The response times were recorded from the moment the test question appeared on the screen. Therefore, participants had no knowledge what type of questions, if any, they were going to answer when reading each sentence. The first type of test question was related to grammaticality. Subjects answered ‘Yes’ or ‘No’ to the question “Was this sentence correct?” As the main difference between simple and complex sentences was in the intervening material within the subject–verb dependencies and the grammaticality question could be answered without reading the intervening sentence material therefore, subjects were presented with an additional test question. This second type of test question pertained to whether one (always a noun, e.g., “a szoba” ‘the room’) occurred in the sentence. Subjects responded with a “yes” or “no” answer as to whether the target word occurred in the sentence. After each block, feedback was given to the subjects about their accuracy. Participants were presented with a practice block of an additional 20 sentences in the beginning of the study.

Subjects were tested individually in a dimmed, sound-attenuating booth. They were seated in a comfortable reclining chair. Participants were instructed to read a series of sentences presented on a computer screen placed in front of them. All sentences were self-paced: when the subjects were ready to start, they pushed a button and the sentence presentation started. At the beginning of each trial a fixation cross was displayed for 400 ms. Sentences were presented in the center of the computer screen, word by word in white lower case letters (Arial, font size 20) against a dark background. Viewing distance was approximately 100 cm and the stimuli subtended a visual angle of 3° horizontally and 0.5° vertically. Each word was presented for 400 ms, followed by a blank screen for 400 ms before the next word

appeared. The testing session began with a short practice block. The experimental trials were presented in 10 blocks of approximately 8 min each. Subjects were given short breaks between the blocks.

3.2. Electroencephalogram (EEG) recording

The acquisition of bioelectrical signals was performed by means of a 32-channel EEG recording system (BrainAmp amplifier and BrainVision Recorder Software, BrainProducts GmbH). Recording electrodes were mounted in an elastic electrode cap according to the 10–20 electrode placement system at the following positions Fp1, Fp2, F9, F7, F3, Fz, F4, F8, F10, FC5, FC1, FC2, FC6, T9, T7, C3, Cz, C4, T8, T10, CP5, CP1, CP2, CP6, P7, P3, P4, P8, O1, O2, P9, and P10. The reference electrode was at Pz, whereas the ground was placed between Fz and Fpz, on the midline. Eye movements were monitored on sites Fp1 and Fp2. The contact impedance was kept below 5 k Ω at each electrode site. The signals were recorded continuously with a bandpass from 0.01 to 70 Hz and the sampling rate was 500 Hz.

3.3. Data analysis

The EEG was re-referenced to the common average reference of all electrodes (Picton et al., 2000). Offline analysis of the data was done with the Neuroscan 4.3 Software using the following steps: after applying a low-pass filter (15 Hz), the EEG data were segmented into epochs of 950 ms (–150 ms before stimulus onset to 800 ms after). Artifact correction criteria were set to $\pm 75 \mu\text{V}$. The segmented epochs were then averaged by each condition and baseline corrected to the 150 ms pre-stimulus period. For the multiword cumulative analysis a 200 ms baseline was used (see Fig. A in the Appendix). Repeated-measures analyses of variance (ANOVAs) were performed with the purpose of comparing amplitudes between the ERP patterns elicited by the main factors. Amplitude was measured as the mean amplitude within a particular time interval. To decrease the number of comparisons performed in the ANOVAs, the original 32 scalp locations were reduced to 7 regions of interest (ROIs). The 7 ROIs were created by grouping the electrodes into spatially homogenous clusters. ROIs comprised equal number of electrodes. Left Anterior, LA (F9, F7 and F3), Central Anterior, CA (Fz, FC1 and FC2), Right Anterior, RA (F4, F8 and F10), Central, C (Cz, C3, C4) Left Posterior, LP (P9, P7 and P3), Central Posterior, CP (Pz, CP1 and CP2), Right Posterior, RP (P4, P8 and P10). A schematic head figure (Fig. 1.) shows the 7 ROIs. The peak latencies were defined separately in each condition for all the analyzed words in the sentence using the global field power calculation² (GFP, Lehmann and Skrandies, 1980).

A 40 ms interval was then calculated around each peak to measure the amplitude in each individual, in each condition for each examined word. To compare component amplitudes, three-way repeated measures analysis of variance (ANOVA) was calculated (Statistica 7 software) in each time window with factors of Sentence Type (Simple vs. Complex), Grammaticality (Grammatical vs. Ungrammatical) and ROI (Left Anterior, LA (F9, F7 and F3); Central Anterior, CA (Fz, FC1 and FC2); Right Anterior, RA (F4, F8 and F10); Central, C (Cz, C3 and C4); Left Posterior, LP (P9, P7 and P3); Central Posterior, CP (Pz, CP1 and CP2); Right Posterior, RP (P10, P8 and P4). Greenhouse–Geisser adjusted univariate test was used as appropriate and the corrected p-value was reported together with the original degree of freedom. Tukey HSD post-hoc analyses were performed to analyze further the significant effects. Only those interactions are reported for which the further posthoc analyses revealed significant dissimilarity of the levels of the interacting factors.

²Global Field Power (Lehmann and Skrandies, 1980) is a global measure of the electric field quantifying the amount of activity, therefore it provides information at which time point there is a maximum strength of the potential field.

4. Results

The overall accuracy of the filler and experimental sentences was high. 94% (SD = 1.0) of the tested sentences were correctly classified in the well-formedness judgment task. 93% (SD = 0.6) of the “intervening word” questions were answered correctly, indicating that subjects were reading and comprehending the visually presented sentences. Considering the low error rate (6%–7%), and the fact that both type of questions appeared in only 15% of the total 400 sentences, all experimental items were included in the ERP analyses, irrespective of the answer to the questions.

Table 2 summarizes the component peaks identified with using the GFP method (Lehmann and Skrandies, 1980, 1984) for the intervening first e.g., “a sötét” ‘the dark’ (simple condition) and “akié” ‘whose’ (complex condition), second, e.g., “üres” ‘empty’ (simple) and e.g., “a pöttyös” ‘the dotted’ (complex condition) and third, e.g., “szobában” ‘the room-INE’ (simple condition) and e.g., “sál” ‘scarf’ (complex condition), respectively.

4.1. ERPs time-locked to first word of the intervening sentence material

The first word of the intervening sentence material was either an adjective e.g., “a sötét” ‘the dark’ in the simple or a relative pronoun “akié” ‘whose’ in the complex condition. Fig. 2 presents the ERPs for the first word of the intervening linguistic material in the different conditions. In case of additional WM load are required for the complex structures, ERPs differences are expected to appear at this point because the relative pronoun “akié” ‘whose’ indicates a clause, while the adjective e.g., “a sötét” ‘the dark’, in the simple condition, doesn't. Namely, an anterior negativity is predicted, that may be overarching the whole clause in the complex condition but not in the simple condition. Three peaks were identified by the GFP for the first intervening word, in each condition, around 290; 400 and 600 ms post stimulus. Average amplitudes were calculated by using a 40 ms window around each peak in each condition, separately.

In the first early time window around 290 ms, the ERPs were more positive for the complex condition (“akié” ‘whose’) than for the simple condition (“sötét” ‘dark’), main effect of Sentence Type, $F(1,13) = 13.902$, $p < 0.025$. This early positivity was the most pronounced at LP (P9, P7, P3) and RP (P4; P8, P10) ROIs, main effect of ROI, $F(6,78) = 22.355$, $\epsilon = 0.458$, $p < 0.001$. Furthermore, while at the LP (P9, P7, P3) ROI a more positive peak was elicited for the simple condition, at the CP (Pz, CP1, CP2) ROI, this positivity was enhanced by the complex condition, revealed by a Sentence Type and ROI interaction, $F(6,78) = 8.917$, $\epsilon = 0.493$, $p < 0.001$.

In the second (around 400 ms) and third (around 600 ms) time windows, Sentence Type or Grammaticality did not enhance the amplitude of the ERPs at any ROI. In the second time window, there was a significant ROI main effect. $F(6,78) = 19.889$, $\epsilon = 0.572$, $p < 0.001$. In the third time window, there was also a main effect of ROI, $F(6,78) = 4.092$, $\epsilon = 0.424$, $p = 0.018$.

4.2. ERPs time-locked to second word of the intervening sentence material

The second word of the intervening material in both simple and complex conditions was an adjective; e.g., “a pöttyös” ‘the dotted’ (complex condition) and e.g., “üres” ‘empty’ (simple condition). Fig. 3 shows the ERPs for the second intervening word. ERP differences at this point of the sentence were predicted, namely an anterior negativity or a sustained negativity overarching the intervening words within the subject–verb dependency, based on previous results (e.g., Fiebach et al., 2002), as the preceding word in the complex condition (the relative pronoun “akié” ‘whose’) builds up an expectation for a clause.

The peaks were identified by GFP in each condition separately, at approximately ~280; 400 and 600 ms.

In the first time window, approximately, ~280 ms, there was no significant effect of Sentence Type or Grammaticality revealed. There was a main effect of ROI, $F(6,78) = 37.467$, $\epsilon = 0.415$, $p < 0.001$.

In the second time window around 400 ms, the complex condition elicited a more negative peak at CP (Pz, CP1, CP2) ROI than the simple condition, Sentence Type and ROI interaction, $(6,78) = 6.250$, $\epsilon = 0.454$, $p = 0.002$. There was also a main effect of ROI, $F(6,78) = 31.019$, $\epsilon = 0.498$, $p < 0.001$.

In the third time window, at approximately, ~600 ms, a more positive peak was elicited for the complex condition compared to the simple condition, main effect of Sentence Type, $F(1,13) = 6.483$, $p = 0.025$. At the anterior ROIs (LA, CA and RA) ERPs were more positive for the complex than for the simple condition, however, at the parietal ROIs (LP and RP), ERPs were more negative for the complex than for the simple condition. This was revealed by a Sentence Type and ROI interaction, $F(6, 78) = 21.320$, $\epsilon = 0.406$, $p < 0.001$. Interestingly, ERPs were also more negative for the ungrammatical than for the grammatical condition, in the third time window, main effect of Grammaticality, $F(1,13) = 5.0839$, $p < 0.042$.

4.3. Third word of the intervening material

The third word was either a noun, e.g., “szobában” ‘room-INE’ in the simple condition, or a NP e.g., “a sál” ‘the scarf’ in the complex condition. Fig. 4 shows the ERPs for the third word of the intervening material. Three time windows were identified with the GFP method, around 280, 400 and 600 ms. In none of these time windows were an effect of Sentence Type or Grammaticality found for the third intervening word. In the first time window, there was a ROI main effect, $F(6,78) = 33.590$, $\epsilon = 0.400$, $p < 0.001$. In the second time window, there was a main effect of ROI, $F(6,78) = 34.47$, $\epsilon = 0.463$, $p < 0.001$. In the third time window, there was a ROI main effect, $F(6,78) = 10.531$, $\epsilon = 0.435$, $p < 0.001$.

4.4. Main verb

When encountering the main verb, each sentence could be judged grammatical or ungrammatical, depending on whether the sentence initial noun and the verb agreed in number. The grand-averaged ERP waveforms evoked by the main verb “ül” ‘sits’ (verb onset marked by vertical line) for the four conditions are displayed in Fig. 5. In the earlier time window, a negativity peaking around 390 ms (LAN) was followed by a later positive component peaking around 610 ms (P600). To compare latency differences, the minimum responses at F3 (for LAN) and maximum responses at Pz (for P600) were analyzed using the same time windows as were used for the amplitude comparison. Table 3 summarizes the peak latencies in each condition.

4.5. LAN

The complexity of the intervening sentence material between the subject and the verb did not affect the amplitude of the negativity elicited by the main verb in the early time window. This negativity however, showed an effect of grammaticality. The amplitude of LAN was enlarged when evoked by ungrammatical compared to grammatical sentences, main effect of Grammaticality, $(F(1, 13) = 9.461, p < 0.008)$. This effect was largest at the central anterior region CA(Fz, FC1, FC2), main effect of ROI, $F(6,78) = 26.936$, $\epsilon = 0.494$, $p < 0.001$. At CA (Fz, FC1, FC2) ROI, ungrammatical sentences elicited a more negative amplitude of LAN than grammatical sentences revealed by a Grammaticality and ROI interaction, $F(6,78)$

$= 5.867$, $\epsilon = 0.529$ $p < 0.001$. The latency of LAN was longer when evoked by ungrammatical compared to grammatical sentences, main effect of Grammaticality, $F(1, 13) = 22.779$, $p < 0.001$.

Although LAN elicited by grammatical violations is usually an anterior negativity, it has also been found with more central focus (e.g., Kaan, 2002). In the current study, the central anterior negativity elicited by the main verb was only sensitive to grammatical violation and therefore we interpret it as LAN.

4.6. P600

The complexity manipulation did not influence the amplitudes of the ERPs in the late time window; there was no significant effect of Sentence Type. The parietal positivity was the most pronounced at the centroparietal CP (Pz, CP1, CP2) ROI, main effect of ROI, $F(6, 78) = 4.794$, $\epsilon = 0.389$ $p < 0.012$). The amplitude of this parietal positivity at CP (Pz, CP1, CP2) ROI was larger for the Ungrammatical condition than for the Grammatical condition, Grammaticality and ROI interaction, $F(6, 78) = 11.756$, $\epsilon = 0.355$ $p < 0.001$. Furthermore, in the Ungrammatical condition, there was also a negative-going potential at the LA (F9, F7, F3) ROI in this late time window, Grammaticality and ROI interaction, $F(6, 78) = 11.756$, $\epsilon = 0.355$, $p < 0.001$. Overall, the late positivity peaked later when elicited by the Ungrammatical condition than the Grammatical condition, Grammaticality main effect, $F(1, 13) = 14.205$, $p < 0.003$. Ungrammatical sentences elicited a longer latency of P600 than Grammatical sentences in the simple condition, Sentence Type and Grammaticality interaction, $F(1, 13) = 5.355$, $p < 0.037$.

4.7. Summarizing the results

The single-word, non-cumulative analysis of the intervening sentence material (a prepositional phrase in the simple and an embedded clause in the complex condition) resulted in local differences of the ERPs. The first word of the intervening linguistic material revealed a centro-parietal positivity around 290 ms that was larger for the relative pronoun “akié” ‘whose’ (complex condition) than for the adjective e.g., “a sötét” ‘the dark’ (simple condition). Furthermore, this positivity was enlarged at the LP (P9, P7, P3) ROI for the simple condition and at CP (Pz, CP1, CP2) ROI for the complex condition.

The second word of the intervening material between the subject and the verb were adjectives in both simple and complex conditions. At around 400 ms, a larger centro-parietal negativity was revealed for the complex condition compared to the simple condition. Around 600 ms, a larger anterior positivity was revealed for the complex condition compared to the simple condition. At the anterior ROIs, ERPs were more positive, while at the parietal ROIs ERPs were more negative for the complex than for the simple condition.

The comparison of the third word, a noun-INE (simple condition) and a NP (complex condition) did not reveal any significant differences.

At the main verb, LAN and P600 were enlarged by the Ungrammatical sentences however; complexity did not affect the neurophysiological responses.

5. Discussion

The objective of the current study was to test Hungarian subject–verb dependencies by manipulating the complexity of the intervening sentence material, as well as the number agreement between the subject and the verb. To this end, we tested whether there are locality effects in Hungarian. Processing Hungarian dependencies is of interest because Hungarian is a case-marking, topic prominent language, permitting different word orders (É-Kiss, 2002;

Kálmán, 1985). Based on previous studies, locality effects were predicted for complex vs. simple sentences, indexed by LAN or SAN, indicating additional resource requirements (e.g., Fiebach et al., 2002; King and Kutas, 1995; Kluender and Kutas, 1993). Furthermore, the amplitude of P600 was expected to be enlarged (e.g., Kaan et al., 2000; Münte et al., 1997) and the latency longer (Phillips et al., 2005) for the more complex structures indexing integration difficulties (Kaan et al., 2000).

In our study, however, the complexity of the intervening sentence material did not affect the amplitude or the latency of the ERPs evoked by the main verbs in either the early or the late time windows. These results are consistent with studies that also found no enhancement of LAN (Gunter et al., 1997) or P600 amplitudes (Kaan, 2002; Phillips et al., 2005; Vos et al., 2001) when compared the processing of simple and complex sentence structures. Grammaticality, however, did influence the amplitude and latency of the LAN and the P600 components in the current study, in line with previous studies (see Hagoort, 2003).

Taken together these results suggest that the positive-going ERP component peaking around ~290 ms from the onset of the first word of the intervening material most likely reflects lexical class differences between the relative pronoun (complex condition) and the adjective (simple condition) rather than maintenance of the first dependent in WM. Furthermore, at the second word, considering the fact that adjectives appeared in both simple and complex conditions, the enlarged amplitude of the negativity around 400 ms may indicate word–frequency or cloze probability differences between the previous word(s) and the second intervening word in the different conditions. It is possible that the positivity around 300 ms and the negativity around 400 ms found for the first and second intervening words, respectively indicate lexical differences rather than sentence level processing differences. One reason is that there was no transient or slow anterior negativity revealed for the first and second intervening words, which should have spanned over the whole intervening sentence material. Furthermore, neither the third word of the intervening material nor the main verb revealed differences between simple and complex conditions. To this end, there was no proof of an anterior holding online or maintenance negativity for the intervening sentence elements within the dependencies (e.g. Fiebach et al., 2002) in the current study (see Fig. A in the Appendix).

LAN and P600 elicited by the main verb were modulated by grammaticality; ungrammatical sentences elicited larger amplitudes and longer latencies than grammatical sentences. A syntax first model proposes that LAN between 300–500 ms indexes morphosyntactic processes (Friederici, 2002). According to a lexicalist view, LAN is elicited when the binding of ‘lexically specified syntactic frames’ is precluded e.g., because the grammatical features do not match (Hagoort, 2003; based on the model of Vosse and Kempen, 2000). The later P600 on the other hand, reflects ‘reanalysis and repair’ processes (Friederici, 2002), or the time to select the final links from the competing candidates (Hagoort, 2003). However, some suggest that grammatical violations simply reflect some sort of general “error detection” or “attentional shift” (Thierry et al., 2003). This idea can be linked to studies suggesting that LAN (Hoen and Dörmény, 2000) and P600 (e.g., Christiansen et al., in press) are not language specific.

Interestingly, in some previous Dutch studies, similar to our results, LAN (Gunter et al., 1997; Kaan, 2002) and P600 (Kaan, 2002; Vos et al., 2001) elicited by grammatical violations were not enlarged by syntactic distance and/or sentence complexity.

It is difficult to tell to what extent these results are specific to the configuration of the languages, considering that languages might be more different than previously assumed (Evans and Levinson, 2009). Dutch word order is regarded as being more similar to German

than to English word order³. The current results provide evidence that Hungarian subject–verb dependencies that are interrupted by a complex rather than a simple word sequence do not involve extra processing requirements as was traditionally assumed (Grodner and Gibson, 2005).

One of the shortcomings of the current study, similarly to most ERP language studies, is that word and word sequence frequencies (e.g., subject–verb pairs) were not taken into account. For example, in previous studies, when frequent adjacent subject (personal pronoun)–verb pairs were selected by using Google counts, response times for object–relative clauses were shorter as compared to similar sentences with less frequent subject–verb pairs (Reali and Christiansen, 2007). Furthermore, some recent studies suggest that people show sensitivity to the co-occurrence probability of even larger (four-word) sequences (Arnon and Snider, 2010; Tremblay and Baayen, 2010). The limitation of the current study is that neither the frequency and cloze probability of each word of the intervening sentence material, nor the co-occurrence probability of the subject–verb pairs was controlled for⁴. Further research is needed to fully address these issues.

The current results are at odds with the DLT (Gibson, 2000). Instead, our results are consistent with studies suggesting that representations of previously occurring sentence materials are retrieved by a content-addressable mechanism (McElree, 2000; McElree et al., 2003).

Behavioral studies have suggested that intervening words within dependencies are able to facilitate processing (i.e., anti-locality effects, e.g., Konieczny, 2000; Vasishth and Lewis, 2006), due to the fact that with the help of the intervening sentence material between noncontiguous dependencies, more precise predictions can be made for the upcoming second element (Konieczny, 2000).

In the current study, complex sentences with an intervening clause did not have an effect on the integration of the subject–verb dependency, compared to simple sentences with an intervening prepositional phrase. Similarly, in other ERP studies, distance and/or complexity manipulation did not enlarge LAN (e.g., Gunter et al., 1997; Kaan, 2002) or P600 (e.g., Kaan, 2002; Vos et al., 2001) elicited by ungrammatical structures.

6. Conclusion

Our results are inconsistent with theories suggesting that distance between non-contiguous dependencies increases processing cost (e.g., Gibson, 2000). We found, as indicated by the LAN-P600 complex, that the complexity of the intervening sentence material between the subject and the verb did not affect the ease of integration. The results of the current study are compatible with the approach describing sentence processing by a content-addressable operation (such as McElree, 2000).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

³Dutch and German have almost the same word order (Swan and Smith, 2001, p.6).

⁴For instance, we have no information on how often Hungarian speakers use the word “akié” ‘whose’ in different contexts, but we know that the relative frequency of the word “akié” is very low: 0.00000077 (980 occurrences in a web corpora of 1272661305 tokens according to Halácsy et al., 2004). Nor have we information on the cloze probability of the words in the different conditions.

Acknowledgments

This work was supported by the Hungarian Research Fund, (OTKA 47381 grant) and the National Institutes of Health (grant R01 DC004263). Many thanks to László Kálmán, Dr. Péter Rebrus, Viktor Trón, and the anonymous reviewers for their valuable comments on a previous version of the manuscript. We are grateful to Bertalan Dankó for his technical help with analyzing the data and to Grace C. Sadia for her help with averaging the 1st, 2nd, 3rd, and 4th words. We are also grateful to Gabriella Baliga for her help with data collection. Request for reprints should be addressed to Hajnal Jolsvai, Cornell University, Psychology Department, 225 Uris Hall, Cornell University, Ithaca NY 14853–7601.

Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10. 1016/j.ijpsycho. 2011.06.010.

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Fig. 1.

The schematic head figure shows the 7 ROIs which were created by grouping the electrodes into spatially homogenous clusters. ROIs comprised equal number of electrodes. Left Anterior, LA (F9, F7 and F3), Central Anterior, CA (Fz, Fc1 and Fc2), Right Anterior, RA (F4, F8 and F10), Central, C (Cz, C3 and C4) Left Posterior, LP (P9, P7 and P3), Central Posterior, CP (Pz, Cp1 and Cp2), Right Posterior, RP (P4, P8 and P10) ROIs were used.

Fig. 2.

ERPs for the first intervening word within the subject–verb dependency which was either an adjective (e.g., “a sötét” ‘the dark’) in the simple condition or a relative pronoun (“akié” ‘whose’) in the complex condition. Negativity is plotted downwards.

Fig. 3.
ERPS for the second intervening words (both adjectives) in the different conditions.
Negativity is plotted downwards.

Fig. 4. ERPs for the third intervening words in the different conditions: e.g., “szobában” ‘room’-INE’ in the simple and e.g., “sál” ‘scarf in the complex condition. Negativity is plotted downwards.

Fig. 5. Averaged ERPs from the onset of the main verb marked by vertical line for 21 electrodes up to 800 ms. Negativity is plotted downwards.

Table 1

Examples of each type of sentence in the Simple Grammatical, Simple Ungrammatical, Complex Grammatical and Complex Ungrammatical conditions.

Simple Grammatical:

“A katona [NP, singular, 3rd person] a sötét üres szobában ül [verb, singular, 3rd person].” “*The soldier the dark empty room-INE sits.*”

Simple Ungrammatical:

“A katonák [NP, plural, 3rd person] a sötét üres szobában ül [verb, singular, 3rd person] (instead of **ülnek**/plural, 3rd person).” “*The soldiers the dark empty room-INE sits.*”

Complex Grammatical:

“A katona [NP, singular, 3rd person] akié (whose) a pöttyös sál ül [verb, singular, 3rd person].”

“*The soldier whose the black dotted scarf (is) sits.*”

Complex Ungrammatical:

“A katonák [NP, plural, 3rd person] akiké (whose[PL]) a pöttyös sál ül [verb, singular, 3rd person] (instead of **ülnek**/plural, 3rd person).”

“*The soldiers whose[PL] the black dotted scarf (is) sits.*”

Table 2

shows the peak latencies for each word of the intervening linguistic material in each condition.

Word	Window	Simple		Complex	
		Gram	Ungram	Gram	Ungram
1	1	298	288	302	296
1	2	410	404	414	396
1	3	586	580	590	580
2	1	292	300	306	294
2	2	412	414	400	394
2	3	526	522	584	586
3	1	290	300	302	300
3	2	420	394	420	420
3	3	522	530	530	526

Table 3

shows the peak latencies for the main verb in each condition.

Window	Simple		Complex	
	Gram	Ungram	Gram	Ungram
Early	385	393	385	399
Late	615	622	624	624