Processing of Multiple Long-Distance Dependencies in Russian: an EEG Study

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Long-distance dependencies in ERPs have been known to elicit sustained anterior negativity (SAN) and P600 effects [1-4, 8-11]. However, the exact interpretation of these ERP effects is still up for debate. We used Russian to conduct the first EEG study of multiple long-distance dependencies to disambiguate the functional interpretation of the following effects:

(1) SAN: SAN connecting a displaced wh-element and its gap has traditionally been interpreted as an index of syntactic working memory load [1-4]. More recent studies have questioned the functional interpretation of SAN in long-distance dependencies, either failing to replicate the same effect [5] or showing a decrease in amplitude of the effect due to contextual support [6-7].
(2) P600: The positive-going voltage deflection at the gap site (usually measured at a subcategorizing verb) has been interpreted as an index of syntactic integration difficulty reflecting the number of syntactic operations involved in closing the dependency [8-9].
(3) Phasic left-anterior negativity (LAN): Several studies have found a transient LAN at the post-gap position [1-3, 10-11], attributing it to a retrieval process. This raises questions about the difference in the mechanisms reflected by SAN and LAN, and also renders the syntactic integration interpretation of the P600 at the preceding position problematic.

Previous ERP studies compare the presence of one long-distance dependency to its absence, making it hard to distinguish between different possible interpretations of known ERP effects. Unlike other previously examined languages, Russian allows multiple wh-elements to be displaced to the left periphery of the sentence, creating the possibility of a three-way distinction: no dependency vs. a single dependency vs. multiple dependencies of the same kind (Table 1). We used embedded *why*-questions as a control condition, rather than typically used embedded *yes/no* questions, to avoid a structural ambiguity: in Russian, the complementizer *that* (*chto*) and the inanimate wh-object *what (chto)* are syncretic. 120 stimulus sentences and 120 filler sentences were presented via RSVP to native Russian speakers (n=27).

We ran repeated-measures by-subjects ANOVAs to test the effects of the number of long-distance dependencies on the three components discussed above:

(1) A significant left-lateralized SAN effect (300-1300 ms from onset of the 2nd wh-word) was found for multiple long-distance dependencies compared to the single and no-dependency conditions ($p < 0.044$); there were no significant differences between the latter two conditions (Figure 1).
(2) A P600 effect (600-1000 ms post verb onset) for multiple and single dependencies was observed, compared to the no-dependency condition ($p < 0.024$), but no statistically significant differences emerged between the multiple and single dependency conditions (Figure 2).
(3) Both multiple and single dependencies elicited a phasic LAN effect (300-500 ms post onset of the post-gap position at 'only') compared to the no-dependency condition ($p < 0.014$) (Figure 3).

The multiple and single wh-dependency conditions patterned differently with respect to each other at the opening vs. the close of the dependency. At the beginning of the dependency, a SAN effect was elicited by multiple but not by single wh-dependencies compared to *why*-questions, which arguably form no dependency. This suggests that SAN is not simply a response to the formation of a syntactic dependency, casting further doubt on its functional interpretation as purely syntactic in nature. In contrast, the lack of a P600 difference between multiple and single wh-dependencies at the verb position marking the end of the dependency raises doubts about an interpretation of the P600 as an index of syntactic integration difficulty: there should be more syntactic material to integrate in a multiple vs. a single wh-dependency. We tentatively suggest that the P600 may instead be an index of an all-or-nothing gap identification mechanism insensitive to the amount of associated syntactic information. This interpretation of the P600 effect at the subcategorizing verb is also more consistent with a subsequent retrieval mechanism as indexed by a phasic LAN at the following position in multiple and single dependencies. Interestingly, the similar lack of a difference between multiple and single dependencies at the post-gap position ('only') suggests that, if LAN indeed indexes retrieval, then the nature of the retrieved information must be independent of the number of completed dependencies.

Table 1. Example Stimuli. Crucial positions are in gray. Some words within [ ] omitted for brevity.

		1st wh	2nd wh		verb	gap	
No-dependency	[Профессор…] спросил [professor$_{NOM}$…] asked	нас, us	почему why	[студент…] уверенно [student$_{NOM}$…] strongly	порекомендовал recommended	только only	[первого…]. [first$_{ACC}$…]
"The professor of biology asked us why the distance-education student strongly recommended only the first tutor?"							
Single dependency	[Профессор…] спросил [professor$_{NOM}$…] asked	нас, us	кому who$_{DAT}$	[студент…] уверенно [student$_{NOM}$…] strongly	порекомендовал recommended	только __$_{DAT}$ /only	[первого…]. [first$_{ACC}$…]
"The professor of biology asked us who the distance-education student strongly recommended only the first tutor to?"							
Multiple dependencies	[Профессор…] спросил, [professor$_{NOM}$…] asked	кого whom$_{ACC}$	кому who$_{DAT}$	[студент…] уверенно [student$_{NOM}$…] strongly	порекомендовал recommended	только __$_{DAT}$__$_{ACC}$ /only	[первого…]. [first$_{GEN}$…]
"The professor of biology asked who the distance-education student strongly recommended to whom only on March 1st?"							

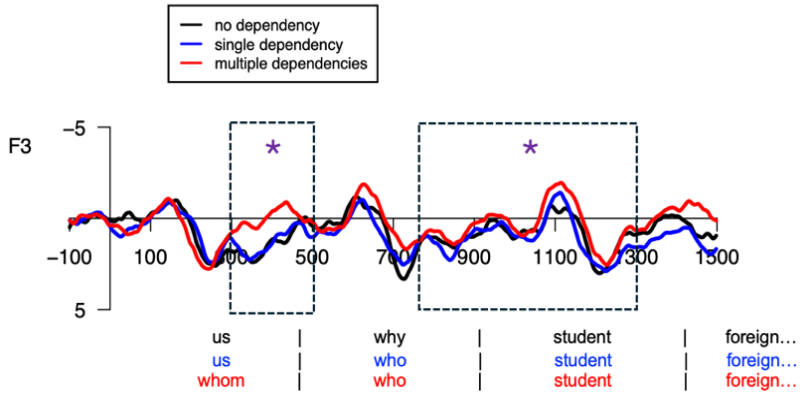

Figure 1. LAN and SAN at the first and second wh-phrases, respectfully.
Grand-averaged ERPs at F3 relative to first wh-position in multiple wh-condition (*whom*), waveforms filtered (20 Hz lp) for visualization, first rectangle = 300-500 ms interval, second rectangle = 750-1300ms interval.

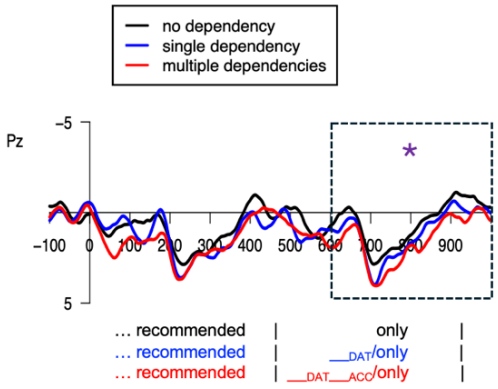

Figure 2. P600 at the embedded verb.
Grand-averaged ERPs at Pz relative to the embedded verb position (*recommended*), waveforms filtered (20 Hz lp) for visualization, rectangle = 600-1000 ms interval.

Selected references: **[1]** Kluender & Kutas, 1993a, Journal of Cognitive Neuroscience; **[2]** King & Kutas, 1995, Journal of Cognitive Neuroscience; **[3]** Kwon et al., 2013, Language; **[4]** Fiebach et al., 2002, Journal of Memory and Language; **[5]** Cruz Heredia et al., 2022, *Neurobiology of language*; **[6]** Yano & Koizumi, 2018, *Language, Cognition and Neuroscience*; **[7]** Yano & Koizumi, 2021, *Cognition and Neuroscience*; **[8]** Kaan et al., 2000, Language and Cognitive Processes; **[9]** Phillips et al., 2005, Cognitive Brain Research; **[10]** Felser et al., 2003, Brain and Language; **[11]** Ueno & Kluender, 2009, *Brain Research*.

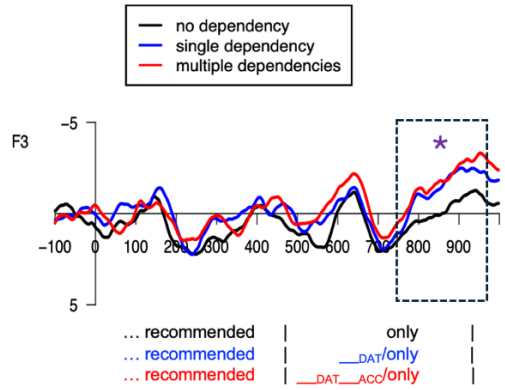

Figure 3. LAN at the post-verb gap position (*only*).
Grand-averaged ERPs at F3 relative to the embedded verb position (*recommended*), waveforms filtered (20 Hz lp) for visualization, rectangle = 750-950 ms interval.