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Quantifier scope in sentence prosody?

A view from production

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Abstract: Logical scope interpretation and sentence prosody exhibit intricate, yet scarcely studied interrelations across a variety of languages and constructions. Despite these observable interrelations, it is not clear whether quantifier scope by itself is able to directly affect prosodic form. Information structure is a key potential confounding factor, as it appears to richly interact both with scope interpretation and with prosodic form.

To address this complication, the current study investigates, based on data from Hungarian, whether quantifier scope is expressed prosodically if information structure is kept in check. A production experiment is presented that investigates grammatically scope ambiguous doubly quantified sentences with varied focus structures, while lacking a syntactically marked topic or focus. In contrast to the information structural manipulation, which is manifest in the analysis of the acoustic data, the results reveal no prosodic effect of quantifier scope, nor the interaction of scope with information structure. This finding casts doubt on the notion that logical scope can receive direct prosodic expression, and it indirectly corroborates the restrictive view instead that scope interpretation is encoded in prosody only in cases in which it is a free rider on information structure.

Keywords: quantifier scope; sentence intonation; prosodic prominence; information structure; focus

1. Introduction

Sentences containing two quantified expressions (aka "doubly quantified" sentences) often exhibit scope ambiguity.This is illustrated by the following example, in which either of the two argument noun phrases may have logical scope over the other.

(1) a. Exactly two students did each assignment perfectly.

b. 'Exactly two students are such that they did each assignment perfectly.'
two > each

c. 'Each assignment is such that it was done by exactly two students perfectly.'
each > two

In this paper we present a production study that explores the potential role of prosody in the expression of scope. We investigate whether in grammatically scope-ambiguous doubly quantified sentences the distinction between linear (surface) scope and inverse scope interpretation is correlated with differences in intonation.[1]

Although in principle doubly quantified sentences such as (1a) are amenable to both the surface scope and the inverse scope interpretation, a variety of factors are known to limit or bias their interpretation one way or the other. One conspicuous factor is word order: typically a quantifier that linearly precedes another is easier to assign wider scope (Ioup 1975; Fodor 1982; Kurtzman & MacDonald 1993; Anderson 2004). Generally, what underlies the apparent effect of precedence is a structural factor, which only partially overlaps with linear order: namely, surface c-command (Reinhart 1976; 1983). Thematic and grammatical roles are also known to impact scope preferences (Ioup 1975; Filik et al. 2004; these factors are typically intertwined with structural c-command relations). For instance, subjects and agents generally take wide scope more easily than grammatical objects and themes, respectively. The ease with which inverse wide scope is available to a quantified phrase is also affected by the lexical semantic type of the quantifying element. In this regard, Ioup (1975) reports the following hierarchy: each > every > all > most > many > several > a few.[2] Downward entailing quantifiers like *few* have been claimed to categorically reject inverse wide scope (Liu 1997; Beghelli & Stowell 1997).

Some other factors that impact scope preferences are pragmatic in nature. These include world knowledge, as well as the sentence–context relation, and in particular, information structure (IS). The (non-contrastive) topic IS role has frequently been associated with wide scope (Ioup 1975; Kuno 1982; 1991; Kempson & Cormack 1981; Reinhart 1983; May 1985; Cresti 1995; Erteschik-Shir 1997; Krifka 2001; Portner & Yabushita 2001;

[1] Throughout this paper, the term *intonation* is used in a broad sense, interchangeably with *prosody*.

[2] For experimental treatments of the differential scope-taking preferences of different quantifier types, see Filik et al. (2004); Paterson et al. (2008); Bott & Radó (2009) and Radó & Bott (2012).

Ebert & Endriss 2004). The effect of focus as an IS role is decidedly more contentious. It has been linked to narrow scope of the focused element in a range of studies (e.g., Diesing 1992; Kitagawa 1994; Kratzer 1995; Krifka 2001; Cohen & Erteschik-Shir 2002; Pafel 2006). A number of others, however, have associated it with wide scope interpretation May 1988; Williams 1988; Langacker 1991; Deguchi & Kitagawa 2002; Ishihara 2002). According to Erteschik-Shir (1997), the choice crucially depends on the contrastiveness of focus: while non-contrastive focus is related to narrow scope, contrastive focus triggers wide scope.

In view of the potential effects of IS roles like topic and focus mentioned above, the particular question we seek to address in this paper is whether logical scope itself is expressed in intonation autonomously of contextual effects that may impose a topic or focus role on some part of a doubly quantified sentence. A production experiment is presented, drawing on data from Hungarian. We argue that the results cast doubt on proposals according to which the relative logical scope of arguments can be directly encoded in sentence intonation, and thus they indirectly corroborate the restrictive view that logical scope is encoded in prosody only in cases in which scope interpretation is a free rider on information structure.

The paper is organized as follows. Section 2 briefly reviews empirical evidence from a range of languages demonstrating that oppositions in scope interpretation are frequently mapped to intonational differences. We discuss the emerging possibility, placing it in the context of the Y-model of the architecture of grammar, that different intonational patterns that appear to be related to different scope readings may be rooted in differences in information structure. Section 3 presents and analyzes the results of a production experiment that was designed to investigate the research question articulated above, namely, whether logical scope itself may be expressed in prosody autonomously of information structure. To address this question, doubly quantified sentences were placed in different controlled information structural settings. A discussion of the experimental results is provided in section 4. The concluding section, section 5, takes stock and identifies avenues for further research.

2. Scope, intonation and information structure

2.1. Scope interpretation and sentence intonation

In the classical restrictive Y-model of transformational generative grammar, sentence prosody, and phonological form (PHON) more generally, has an interpretive role, similarly to semantic interpretation (SEM). While syntax is (unidirectionally) mapped to both, PHON and SEM are not related to each other directly. Thus, any correlations between relations in SEM and relations in PHON must be mediated by syntax. A central case in point is information structure: differences in information structure are often simultaneously manifested in both SEM and PHON. A mainstream response to this state of affairs within the Y-model is to rely on dedicated features and configurations in the syntax that are interpreted at both interfaces (Jackendoff 1972; Rizzi 1997). As an alternative, it is possible to posit mapping algorithms at both interfaces that are sensitive to the same non-dedicated properties of the syntactic representation (for such a mapping rule at the SEM interface, see Neeleman & van de Koot 2008). While the intonational effects of information structure have been studied extensively both from the perspective of the Y-model and beyond, it has received much less attention whether scope interpretation also affects intonation in systematic ways. If so, that would be another case in which distinctions in SEM are reflected in PHON.

In order to formulate this issue with more precision, it must be taken into account that intonation is affected in systematic ways by constituent structure itself (for a recent overview, see Selkirk 2011). Given the possible effect of syntactic structure on intonation, in cases in which a difference in quantifier scope is represented in terms of constituent structure, the scopal difference might well manifest itself in intonation without that being a direct effect of logical scope. Thus, insofar as such an intonational difference can be derived solely on the basis of the structural difference, it poses no challenge to the Y-model. In the remainder of this section we review instances of scope alternations that are not syntactically encoded in this manner, yet appear to license a divergence in intonational form.

A notable case in point is sentences like (2) in English, which can be uttered either with what Jackendoff (1972) calls an A-accent (a falling tone), or with what he calls a B-accent (a fall–rise) on the subject phrase (see also Bolinger 1965). The A-accent, characteristic of canonical intonation, corresponds to surface scope interpretation (2a), while the intonationally marked B-accent triggers an inverse scope reading (2b).

(2) All politicians are not corrupt.

a. all > not

b. not > all

The phenomenon is not limited to English: similar facts hold in various other languages (see the hat contour in German, Féry 1993; Büring 1997, and in Hungarian, Szabolcsi 1981).

The relation between intonational properties and scope interpretation has also been explored with specific regard to negation and quantified phrases in Greek by Baltazani (2002a;b). She found that prosodic prominence or non-prominence of the quantified phrase correlates with its wide scope and narrow scope interpretation, respectively, with respect to negation.

Prosodic prominence was also shown to influence scope interpretation in doubly quantified sentences in Russian, though in Russian this effect seems to be dependent on word order. In particular, Ionin and Luchkina (2015) found in a perception study that the availability of an inverse scope reading increases, compared to an appropriately matched baseline, when an indefinite quantified phrase occupying a preverbal position in an OVS order is prosodically prominent.

In fact, the claim that prosodic prominence plays a key role in scope disambiguation was put forward in pioneering work on Hungarian sentence prosody by Hunyadi (1981; 1999; 2002). According to Hunyadi's (1999; 2002) analysis, the relative scope of quantifier (or operator) phrases is determined in no small part by prominence relations. In particular, Hunyadi proposes, among others, the key generalization in (3).

(3) If two quantified phrases XP and YP are located within a single intonational phrase IP, then if XP corresponds to the most prominent phonological phrase (= the head) of IP, then XP takes scope over YP.

Hunyadi further suggests that if two quantified phrases XP and YP correspond to the most prominent phonological phrase in two distinct intonational phrases, then their relative scope is determined by independent lexico-semantic factors. To illustrate, consider the scopally ambiguous example in (4), which is assumed to be assigned one of the two intonational structures in (5).[3] In (5a) the post-verbal indefinite object undergoes stress reduction, and the whole sentence forms a single IP. In (5b) the post-verbal object does not undergo stress reduction and it forms a separate IP.

[3] Similarly to English, bare *kevés* corresponds to 'few/little'; while if it is preceded by an indefinite article, it is interpreted as 'a few/a little'.

According to Hunyadi (1999; 2002), (5a) only has a linear scope interpretation, while (5b) corresponds to an inverse scope reading.[4]

(4) Kevés diák olvasott el két cikket is.
few student read.PST VM two paper.ACC DISTR
'Few students read two papers.'

(5) a. (Kevés diák olvasott el két cikket is)$_{IP}$
b. (Kevés diák olvasott el)$_{IP}$ (két cikket is)$_{IP}$

In short, a broad range of observations made in a variety of languages suggest that it is possible for differences in scope interpretation to be matched with differences in intonational form.[5] A crucial question to raise, however, is whether in the instances in which this appears to be the case the two distinct interpretations differ **only** with regard to logical scope, i.e., whether they involve "purely" scopal differences, or the scopal distinctions correlate with information structural distinctions, which may ultimately be responsible for the observable intonational effects. This is the issue to which we turn next.

2.2. The potential role of information structure

It is beyond reasonable doubt that information structure affects sentence prosody in systematic ways (among others, Bolinger 1965; Halliday 1967; Jackendoff 1972; Ladd 1980; Lambrecht 1994). If the intonational differences correlated with scope oppositions turn out to be matched with information structural distinctions that can in themselves account for the intonational facts, then we have no reason to posit any independent mapping algorithm between logical scope (or its dedicated syntactic representation) and intonation.

To take a simple example, the inverse scope reading in sentences of the type illustrated in (2) above is known to be inseparable from the contrastive topic interpretation of the quantfication phrase that c-commands negation in surface structure (for an influential account of how this IS interpretation gives rise to the inverse scope reading, see Büring 1997). As

[4] Abbreviations used in glosses: PST = past tense; ACC = accusative case; VM = Verbal Modifier; DISTR = distributive particle.

[5] For other cases in which scope appears to be correlated with intonational properties, see Sauerland & Bott (2002); Hirotani (2004) and Błaszczak & Gärtner (2005). For reasons of space, we cannot discuss the generalizations made in these works.

the intonation paired with inverse scope is identical to the intonation that is generally correlated with a contrastive topic interpretation, scope itself has no role to play in accounting for the intonational distinction (Ward & Hirschberg 1985; Kadmon & Roberts 1986).[6] Arguably, the differences in sentence prosody matching the scopal oppositions reviewed in the preceding subsection all appear to be related to differences in information structure in much the same way. In the remainder of this section, we briefly flesh out this possibility.

The intonational pattern associated with the inverse scope reading of Russian OVS sentences with an indefinite object uncovered by Ionin and Luchkina (2015) corresponds to the contrastive focus interpretation of the object phrase. Indeed, it was suggested antecendently by Ionin (2003) that a contrastive reading of the pre-verbal indefinite is needed for the inverse scope interpretation to be available.

Similarly, the intonational difference in Hungarian analyzed by Hunyadi as in (5a,b) also reflects an information structural variance. Namely, (5a), in which the post-verbal indefinite is unaccented, arises when the pre-verbal indefinite is focused and the post-verbal indefinite falls within its background.[7] In (5b), on the other hand, either the pre-verbal indefinite is not focused, or if it is, then the post-verbal indefinite is not part of its background.[8] Thus, (5a) may be an answer to (6a), and (5b) can be a reply to (6b).[9]

[6] Kadmon and Roberts (1986, 18) suggest, based on their analysis of the scopal interaction of negation with quantified phrases, that from a processing perspective "[p]rosody does not directly determine the relative scope of operators. Intonation and stress convey partial information about the structure of the discourse, and it is this structure which determines the relative scope [...]."

[7] For an analogous claim about a closely related sentence pattern, see Kálmán (1985, 34). For a discussion of post-focal prominence reduction in Hungarian, see Kálmán & Nádasdy (1994); Vogel & Kenesei (1987), and Varga (2002).

[8] According to Szabolcsi (1997a), an immediately pre-verbal downward entailing numeral indefinite that is accompanied by the inversion of the verb and the verbal particle, as in (4), is not necessarily focused, while according to Surányi (2002) and É. Kiss (2002), it is. The verbal particle represents the most common subclass of a category of pre-verbal elements called Verbal Modifiers (VM). Generally, if an element is placed in an immediately pre-verbal position and a Verbal Modifier appears to the right of the verb, then the element preceding the verb is normally intepreted as a focus.

[9] These questions do not need to be explicit in discourse: it is sufficient for them to be the Question Under Discussion (QUD), or a subquestion of the QUD, at the point of the utterance that serves as an answer to them (Roberts 2012).

(6) a. How many students read two papers?
b. How many papers were read by few students?

Mutatis mutandis, the intonational correlates of the scope of negation with respect to a quantified phrase in Greek, noted above, may also be rationalized in an analogous manner. In her treatment of the prosodic reflection of scope in negated Greek sentences, Baltazani (2002a;b) argues in precisely this vein that the different intonational patterns found to be correlated with different scope readings emerge from differences in information structure, rather than from differences in scope interpretation alone (see also Baltazani 2006).

A distinct possibility that emerges from the foregoing discussion is that different intonational patterns that appear to be related to different scope readings may be rooted in differences in information structure, specifically in the assignment of (contrastive) topic and focus roles within the sentence.[10] If that is so, then special provisions are to be made in order to address the question whether quantifier scope is encoded in intonation. Namely, we need to examine minimal pairs of distinct scope interpretations in which the possibility that the scope difference is in turn associated with an information structural difference is appropriately minimized, or ideally, excluded. The experiment we report on in the next section has been designed with this desideratum in mind.

3. A production experiment

In this section we report on an experiment that was designed to test the relation between quantifier scope and sentence intonation in doubly quantified sentences, addressing the question whether quantifier scope interpetation has an effect on intonation autonomously of the prosodic expression of information structure.

The experiment was carried out in Hungarian. In this language both aboutness and contrastive topics are syntactically marked by fronting to the left periphery of the sentence (É. Kiss 2002). Further, Hungarian has an immediately pre-verbal structural focus position: if an element is placed

[10] Not discussed here are possible alternative treatments of the phenomena reviewed in the previous subsection that would posit that the opposing scope interpretations are dependent on, and brought about by, syntactic differences. É. Kiss (2010) argues in precisely this vein that the intonational difference between (5a) and (5b) corresponds to a structural difference.

here rather than in its canonical position, then it must be intepreted as a focus. A straightforward syntactic clue indicating that a pre-verbal phrase is located in the structural focus position is the inversion of the verb to the left of the Verbal Modifier (VM). Verbal Modifiers are a class of elements that appear to the immediate left of the verb in neutral, broad focus sentences (see É. Kiss 2002). In fact, the structural focus position in Hungarian is associated with a special "identificational" focus interpretation (see É. Kiss 1998). Focus, being a more encompassing notion (definable, for instance, in terms of congruence with a Question Under Discussion, Roberts 2012), includes elements that do not have an identificational function. Non-identificational foci, including contrastive occurrences, do not appear in the structural focus position, but remain syntactically unmarked.

Based on the conclusion reached at the end of the preceding section we investigated the possible effect of scope on intonation in sentences in which it holds of none of the scope-taking elements (nor of any other element in the sentence) that (i) it needs to be interpreted as a topic or it can easily be assigned topic status even without context (see section 1), or (ii) it must be interpreted as a focus or it can easily be assigned focus status even without context (cf. 'few students' in (4) above). Accordingly, the target sentences investigated in the experiment contained no element occupying either a topic or a focus position.

The sentences were inserted in two carefully controlled contextual settings that served to keep their information structure in check. Specifically, the two types of contexts assigned a narrow focus interpretation to one or the other of the two quantified NPs in the sentence, with the rest of the sentence being given as the background. It was predicted that this information structural difference would be reflected in the prosodic realization of the two quantified NPs in terms of at least some of the acoustic parameters that characterize the distinction between focus versus given background information structure status in Hungarian (to which we return in section 3.2.). Furthermore, it was expected that just in case quantifier scope alone systematically affects sentence intonation in a way that is independent of, or additional to, information structure, then we would either find that sentences associated with a linear scope interpretation differ in their prosodic realization from corresponding inverse scope sentences with a matched information structure, or at least scope shows an interaction with information structure in shaping the intonation of the sentence.

The experiment tested sentence prosody in production. This choice was motivated by previous literature. In particular, the influence of prosody, in particular, the potential effect of prosodic prominence relations on scope

interpretation in the perception of doubly quantified sentences has already been investigated in Greek and in Hungarian, by Baltazani (2002a;b) and Gyuris & Jackson (under review), respectively. Both studies included transitive sentences containing a quantified subject and a quantified object. In Baltazani's study, it was varied which one of the two arguments was prosodically focused. In Gyuris and Jackson's sentences, one of the two arguments, a numeral indefinite NP, was invariably focused and occupied a pre-verbal focus position, while the prosodic prominence of the other argument was varied.[11] In Greek, the sentences were presented without a context, while in Hungarian they were presented in a context that was intended to be neutral with regard to both information structure and scope interpretation. No significant effect of prosodic prominence on scope readings was found either in Greek or in Hungarian.

In spite of these results, as Gyuris and Jackson are careful to point out, it is possible that the intonational differences pertaining to scope interpretation are different from what their perception study relied on. More relevantly to our present concerns, it is conceivable that the distinctions that are of significance for scope interpretation obtain less reliably in the perception than in the production of sentence intonation. Or, even assuming that the pertinent cues are perceived, they may not be reliably exploited in experimental tasks requiring participants to match perceived intonational forms with interpretations.

Such asymmetries between perception and production have been recurrent in investigations of focus prosody. With particular regard to the prosodic encoding of quantifier scope, Antonyuk-Yudina (2011) found that although inverse scope was associated in Russian doubly quantified sentences with a marked prosody in production, participants performed poorly in perception in the disambiguation of sentences recorded on their inverse scope interpretation.

3.1. Materials and methods

The critical experimental stimuli involved doubly quantified sentences. Target sentences were constructed in such a way as to avoid variation in any of the biasing factors identified in section 1. Each target sentence in the experiment was scopally ambiguous and had the following properties,

[11] The study also included sentences in which a focused proper name was used instead of the pre-verbal focused numeral indefinite. Prosodic prominence relations had no effect on scope interpretation in this sentence type either.

illustrated in (7) below. It consisted of a bare numeral indefinite subject, followed by a complex transitive verb, in turn followed by a universally quantified object.[12] The complex verb is composed of a verbal particle and a verb, in this default, uninverted order. The predicate was telic, perfective and appeared in the past tense. The object was introduced by the strongly distributive universal quantifier *mindegyik* 'each'. The subject phrase was composed of the numeral *négy* 'four', a noun denoting in the human domain, and a distributive particle *is* (see Szabolcsi 1997). The purpose of using this particle was to enforce a distributive interpretation, making the numeral indefinite subject similar in this regard to the inherently distributive universally quantified object. The distributive particle further ensured that the pre-verbal indefinite could not be construed as an aboutness topic: indefinites marked by the distributive particle must be part of the comment in Hungarian (see É. Kiss 2002). In the absence of such a distributive particle a pre-verbal indefinite argument, followed by a complex verb in an uninverted VM–V order, is normally interpreted as an aboutness topic, a reading that we aimed to avoid. The linear and inverse scope readings of (7) are paraphrased in (7a) and (7b), respectively.

(7) **Négy** előadó is el- énekelte **mindegyik** melódiát.
four singer DISTR VM sang each melody.ACC
FOUR N1 DISTR VM- V EACH N2
'Four singers sang each melody.'

a. 'There were four singers who sang each melody.' four > each (linear)

b. 'Each melody is such that four singers sang it.' each > four (inverse)

Note that the paraphrase of the linear scope reading immediately above entails the truth of the paraphrase of the inverse scope reading, provided that the same fixed set of singers and melodies are involved in the two interpretations. If, however, the sets of melodies paired with the singers on the linear scope reading are disjoint (i.e., if each singer is related to a different set of melodies), then the two scope interpretations are truth-conditionally independent. Indeed, as we spell out below in relation to the visual stimuli, the latter was the case in the critical conditions of the present experiment.

Each target sentence was embedded in a dialogue context. The dialogue was made up of two sentences, each of which was uttered by an imagined interlocutor: Speaker A and Speaker B. Each sentence was

[12] Although Hungarian is a rigid scope language as far as its pre-verbal domain is concerned, post-verbal quantificational phrases may take inverse scope over non-topic pre-verbal arguments (see É. Kiss 2002).

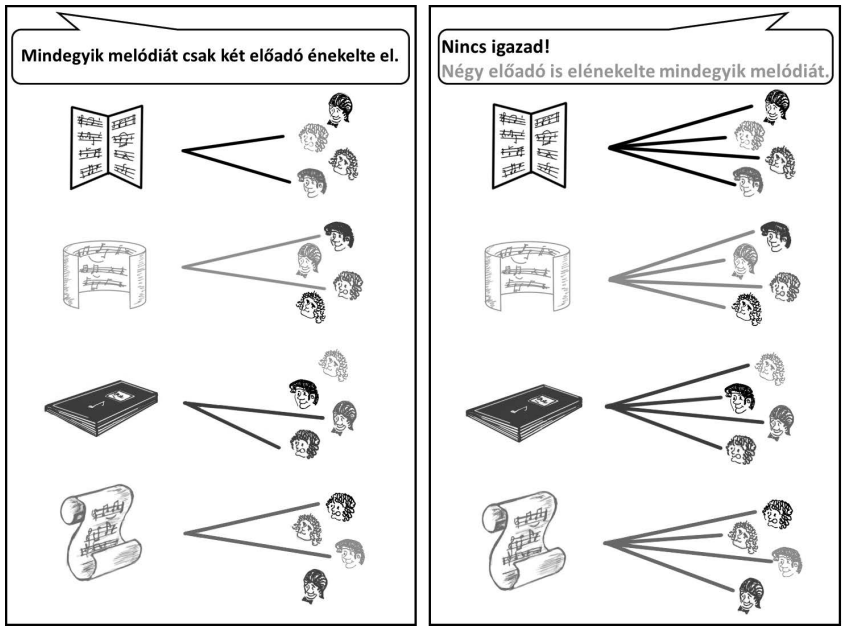

Figure 1: Stimulus containing the dialogue made up of (9) and (12), exemplifying the Indefinite Focus–Inverse Scope condition

accompanied by a diagram that represented its intended meaning. In each trial the target sentence and its context were printed at the top of a display shown to participants on a 22-inch computer screen along with the two images side by side. The images were designed both to fix, and to help participants conceptualize, the intended scopal meanings. Figures 1 and 2 provide a sample of the target displays (with glosses added below the dialogue for convenience).

Bott and Radó (2007) have argued that abstract diagrams made up of dots and lines, similar in structure to those in Figure 1 and Figure 2, serve as highly suitable stimuli in sentence–picture verification tasks that require subtle judgments of quantifier scope interpretation. In a series of experiments testing alternative methods, they found that visual stimuli based only on global natural-looking images that depict complete scenarios without explicitly representing scope relations may introduce scope interpretation biases that result from extralinguistic factors. While their results confirm both the validity of linguistic stimuli involving question–answer pairs and the validity of abstract diagrams involving sets of dots and lines,

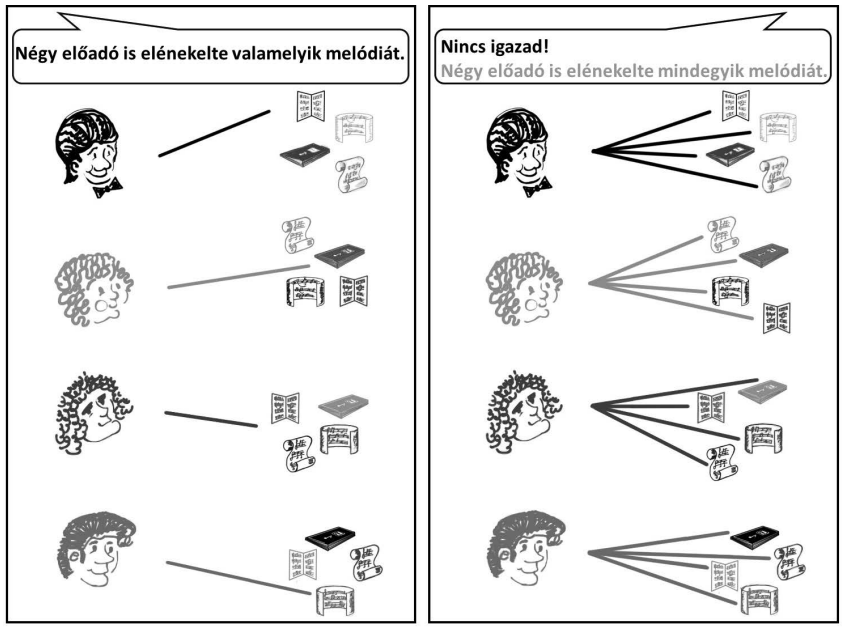

Figure 2: Stimulus containing the dialogue made up of (10) and (12), exemplifying the Universal Focus–Linear Scope condition

they demonstrate that the latter type of stimuli yields more consistent scope judgments across participants, that is, it is more reliable.

Visual stimuli in our experiment explicitly represented scope relations by sets of connecting lines, analogously to Bott and Radó's (2007) dots-and-lines diagrams. In difference to the latter type of stimuli, however, in our diagrams the different sets of individuals and objects were represented by natural-looking images rather than abstract dot symbols. This was done to further aid the correct assignment of the targeted scopal interpretation to experimental sentences.

In each diagram the set of figures that corresponded to the phrase with wider scope (Figure 1: the set of melodies, Figure 2: the set of singers) were arranged vertically at the left-hand side, while the sets of figures corresponding to the narrow scope phrase (Figure 1: the sets of singers, Figure 2: the sets of melodies) were consistently arranged along the right edge. Each member of the "wide scope" set on the left side was linked with straight lines to members of one of the sets on the right-hand side. This served to make prominent the distributive interpretations that were targeted throughout.

Individual figures within both the left-hand side "wide scope" set and the right-hand side "narrow scope" sets were coded with different colours and relative positions, in order to make it conspicuous that they were distinct individuals/objects, rather than the same individual recurring in different events. All lines starting from the same individual/object on the left-hand side were of the same colour as the individual/object itself, and this colour differed from the colour of all the other lines in the picture.

Each set of figures on the right-hand side whose members were linked to some particular individual/object on the left-hand side spatially formed a small group that was separated from other sets of "narrow scope" figures below and above it by a clearly visible amount of extra space. Participants were instructed that differences in colour and shape represented distinct individuals/objects. The colour and spatial position of the figures were varied across the right-hand side sets in order to make sure that these sets were perceived as being disjoint, representing distinct sets of individuals/objects. Thus, for example in the image representing the inverse scope reading of (7), each one of four melodies is linked to a different set of singers. As a result, in this image there is no singer that is connected to more than one melody, which, as required, is consistent with the inverse scope reading of the sentence and contradicts its surface scope reading.

The sentence uttered by Speaker A made a claim about a certain situation. The intended scope relations of Speaker A's context-setting sentence were depicted by the diagram on the left hand side, with the claim made by Speaker A printed above it in a speech bubble. Speaker A's interlocutor, Speaker B was aware of what happened in the relevant situation in reality. This was different from what Speaker A claimed, and it was pictured in the right-hand side diagram, along with a speech bubble containing Speaker B's reaction. Speaker B responded to Speaker A's statement by saying "You're wrong" and continued directly with the target sentence, which made the correction. Speaker B's corrective sentence reflected what happened in reality, which was depicted in the right-hand side diagram. Participants were asked to play Speaker B's part by reading out her/his reaction.

Speaker A's context-setting statement included two quantified NPs. One of these was identical to one of the two quantified NPs that made up the target sentence in the same trial. The other one crucially differed from the other quantified NP of the target sentence, thereby setting up a contrast, but it quantified over the same sets of (animate or inanimate) individuals. As a result, the quantified NP of the target sentence that contrasted with a quantified NP of Speaker A's context-setting sentence

(either the pre-verbal numeral indefinite NP or the post-verbal universally quantified NP) functioned as a contrastive focus.

The scope relations depicted by the diagram illustrating Speaker A's statement paralleled the intended scope relations of Speaker B's target sentence, thus, the two key sentences making up the dialogue did not differ in terms of relative scope. To facilitate the intended scope reading of Speaker A's sentence, its form was chosen in such a way that the scope reading depicted below it always corresponded to a linear, surface scope reading. Facilitating the intended scope reading of Speaker A's utterance in this way served to prime the intended – isomorphic – scope reading of the target sentence: Speaker B's corrective target sentence was congruent with Speaker A's context-setting statement only if the scope relations assigned to the former paralleled those assigned to the latter.

In sum, the independent factors in this experiment included the information structure and the scope interpretation of target sentences, each of which had two levels. Either the pre-verbal indefinite NP or the post-verbal universally quantified NP was assigned narrow focus status (IS: INFOCUS/UNFOCUS), with the rest of the sentence functioning as the background. The targeted scope interpretation was either linear or inverse (SCOPE: LINEAR/INVERSE). Crossing these two factors in a two-by-two design gave rise to four experimental conditions, summarized in Table 1. The dialogues corresponding to these four conditions are illustrated in (8)–(12) below. (8)–(11) contain a sample of the context setting questions in the four critical conditions, uttered by Speaker A. (12) is Speaker B's answer containing a target sentence, which is to be read out by the participants—in separate trials—as a reaction to each of (8)–(11). Figure 2, which accompanied the specific dialogue made up of (9) and (12), exemplifies the visual stimuli containing two contrasting diagrams.

Table 1: The four experimental conditions

	IS	
SCOPE	INFOCUS	UNFOCUS
LINEAR	INFOCUS–LINEAR	UNFOCUS–LINEAR
INVERSE	INFOCUS–INVERSE	UNFOCUS–INVERSE

(8) Indefinite Focus – Linear Scope
A: **Csak két** előadó énekelte el **mindegyik** melódiát.
only two singer sang VM each melody.ACC
'Only two singers sang each melody.'

(9) Indefinite Focus – Inverse Scope
A: **Mindegyik** melódiát **csak két** előadó énekelte el.
each melody.ACC only two singer sang VM
'Only two singers sang each melody.'

(10) Universal Focus – Linear Scope
A: **Négy** előadó **is** elénekelte **valamelyik** melódiát.
four singer DISTR VM.sang one.of.the melody.ACC
'Four singers sang one of the melodies.'

(11) Universal Focus – Inverse Scope
A: **Csak egy** olyan melódia van, amit **négy** előadó **is** elénekelt.
only one such melody is which four singer DISTR VM.sang
'There is only one melody such that it was sang by four singers.'

(12) B: Nincs igazad! **Négy** előadó **is** elénekelte **mindegyik** melódiát.
is.not right four singer DISTR VM.sang each melody.ACC
'You are wrong. Four singers sang each melody.'

Participants were instructed to read out Speaker B's part of the dialogues as a corrective reaction to Speaker A's claim in such a way that it matches the situation depicted by the diagram below it (on the right side), which represents what happened in reality, as opposed to the factually incorrect claim made by Speaker A, depicted below Speaker A's utterance (on the left side). Participants were asked to first read the dialogue and carefully inspect the respective diagrams to make sure that they understand the meaning of both Speaker A's and Speaker B's utterance. They were allowed to read out Speaker B's part as many times as they wanted, until they felt their prosodic realization was adequate. In cases in which the target sentence was read out more than once, only the last rendering was included in our analysis.

Five different lexicalizations of Speaker B's response were created, each of which was paired up with each of the 4 (= 2×2) types of contexts set up by Speaker A's utterance. These 20 critical items were complemented with 40 fillers. The 40 fillers fell into 4 different types, with each type having 10 different lexicalizations. Filler items were superficially similar to critical items, and similarly to critical items, they were varied in a balanced way in terms of Speaker B's targeted scope interpretation (which was either

linear or inverse). By further analogy to critical items, fillers also differed in a balanced manner with regard to whether the focus was associated with an indefinite NP or a universally quantified NP in them, and also whether this focused NP occupied a pre-verbal or a post-verbal position.

Twelve sequences of trials were constructed, each with its own pseudo-randomized order. These sequences only differed with regard to the order of the trials that they were made up of. In every sequence each critical item was followed by two filler items, directly preceding the next critical item. Every sequence contained each of the 5 lexicalizations of the 4 critical conditions, as well as each of the 10 lexicalizations of the 4 types of fillers. Every participant was assigned 4 of the 12 sequences in a balanced way. Thus each participant was presented with the very same critical trial four times, once per sequence, yielding four repeated recordings. As summarized below, 80 critical and 160 filler items were recorded per participant; thus for each of the four critical conditions 160 recordings (8 speakers × 5 lexicalizations × 4 recordings) were made.

(13) a. Critical items
2(SCOPE) × 2(IS) × 5(lexicalizations) × 4(recordings) = 80

b. Filler items
2(SCOPE) × 2(IS) × 10(lexicalizations) × 4(recordings) = 160

Presenting each lexicalization in all conditions to each participant served to restrict item-related variance and thus increased the likelihood of uncovering any systematic prosodic distinctions that speakers might use to differentiate the interpretations.

The recording took place in a soundproof room, using a head-mounted microphone. After the instructions were presented, the experiment started with a short training phase. During the training phase the experimental assistant was available for queries. Participants were allowed to take a short break in between any two of the four sequences.

Eight monolingual speakers (mean age = 25, male = 2, female = 6) were recorded, all of them students. They were recruited from Budapest to participate in the experiment, and received financial compensation for their participation.

3.2. Data analysis and measurements

As reviewed in section 2.1., the most common prosodic device that appears to be employed across languages to express logical scope differences is the manipulation of prominence relations, and this is also the means through

which Hungarian has been claimed to encode the difference between linear and inverse scope, at least in some sentence types (see Hunyadi 1999; 2002). We therefore investigated prosodic prominence relations across the different conditions. In particular, the vowel of the first syllable of the numeral and the universal quantifier as well as each content word was analyzed in all target sentences (VOWEL = FOUR/N1/VM/V/EACH/N2, see (7)). These vowels were selected on the basis of the hypothesis that Hungarian encodes prominence relations in terms of the prominence of stressed syllables, lexical stress is uniformly aligned with the first syllable of words, all content words are lexically stressed by default, pitch accents can only be associated with syllables bearing word-level stress, and all lexically stressed content words are accented by default (i.e., Hungarian is a dense pitch accent language; for a lucid overview, see Varga 2002).

The acoustic cues that were measured in the vowels identified immediately above were parameters commonly associated with relative prosodic prominence at the sentence level in a number of stress-accent languages with intonational pitch accents. These most notably include the scaling of pitch excursion (Sluijter 1995; Sluijter & van Heuven 1996; Ladd 2008), measured in terms of fundamental frequency (F0; F0 maximum and range) and duration.[13] The default accent type in the non-topic part of assertive declarative sentences in Hungarian is a falling accent (analyzed as H*+L by Surányi et al. 2012). As Genzel et al.'s (2015) results suggest that steepness of falls is also associated with prominence (narrow focus is realized with a steeper fall than broad focus, as measured on a designated element), we also calculated the rates of falling realizations for each stressed vowel, and we measured the steepness of these falls.[14]

It must be noted, however, that the prosody of sentence-level prominence in Hungarian is still relatively understudied. Steepness (of falling accents) as well as duration were used as tentative potential measures, because the existing evidence that they play a role in sentence-level prominence-marking in Hungarian is controversial at best. For instance, in Mády's (2012) material steepness played a lesser role in the expression of focal prominence in read speech, and none at all in spontaneous speech. Further, the duration of the accented vowel failed to be exploited systematically for the marking of focus prominence in production experiments

[13] Intensity was not analyzed. Olaszy (2000, 176) argues that "the carrier of prosody in Hungarian dialogue elements is mainly a function of the change in F0. The realization of the correct intensity structure may improve the prosody but not form it."

[14] Olaszy (2002) also suggests that especially prominent falling accents are associated with greater steepness.

performed by Genzel et al. (2015) and Vogel et al. (2015). The phonetic cue that is most likely to be associated with prominence in Hungarian appears to be the scaling of F0 peaks of falling accents. Genzel et al. (2015) found that the F0 maximum of the falling accent is higher when the designated element is realized with focal prominence, than when it is not. The relevance of the F0 maximum of falling accents in prominence-marking in Hungarian is also suggested by Varga (1975), who identifies broad focus accents as a "low fall" (falling from mid to low) and narrow focus accents as a "high fall" (falling from high to low).[15]

The sound files were annotated for segment boundaries automatically using *ProsodyLab Aligner* (Gorman et al. 2011). The following data of each selected vowel were extracted with the acoustic analysis software *Praat* (Boersma 2001): values of F0 maxima and minima, the alignment of F0 maxima and minima within the vowel, pitch range, and duration. The F0 values were transformed into semi tones by speaker (using 20Hz as a base value). The F0 ranges and slopes were calculated using Hz values, in each case subtracting the F0 minimum from the F0 maximum (= F0 range (Hz)), and the time point of the F0 minimum from the time point of the F0 maximum (= F0 slope duration (s)). The F0 range was divided by the F0 slope duration, which yielded the value of the F0 slope (Hz/s). Vowels were categorized into those with falling pitch (i.e., vowels in which the F0 minimum followed, rather than preceded the F0 maximum) and those with non-falling pitch. The proportion of falls was calculated for each vowel by dividing the number of falling realizations with the number of all realizations.

In addition, we searched for any pauses (silent intervals) before and after stressed words, basing ourselves on the assumption that prosodic breaks tend to indicate prosodic boundaries, and prosodic boundaries are not infrequently utilized in languages to mark an immediately preceding or following element as prosodically prominent (Beckman 1996; Jun 2005; 2014; for Hungarian, see Mády & Kleber 2010; for the claim that focus prominence affects prosodic phrasing in Hungarian, see Vogel & Kenesei 1987).

[15] Although Mády's (2015) study failed to detect an effect of focus prominence on F0 maxima in production, this was the only measure that exhibited a significant main effect of focal prominence in perception.

3.3. Results

Pauses required no statistical analysis since the forced aligner did not detect any measurable silent intervals within target the sentences in any of the experimental conditions.

We analyzed the parametric data with Linear Mixed Effect Models (using R, R Development Core Team 2018), with the relative scope of the two quantified phrases (SCOPE: LINEAR or INVERSE), the information structure of the sentence (IS: INFOCUS or UNFOCUS), and the vowel (VOWEL: the first vowel of each content word) as fixed factors, and SUBJECT and ITEM as random factors.[16] Model selection was carried out using stepwise backward elimination based on AIC values, starting from the full model with maximal random effect structure, until the most parsimonious convergent model was reached. Each of the selected models included at least random intercepts for both SUBJECT and ITEM.

Beginning with F0 maxima, the most parsimonious model included IS as a fixed factor, interacting with VOWEL. While Is had a significant main effect ($\chi^2(1) = 11.44;\ p < .001$), SCOPE did not ($\chi^2(1) = .23;\ p = .63$), and Is and VOWEL exhibited a significant interaction ($\chi^2(5) = 16.24;\ p < .01$). No further interactions were found. A *post hoc* test based on pairwise Tukey comparisons of the two levels of IS within the VOWEL factor revealed a significant difference (*t-ratio* $= 4.29$, $p < .0001$) in the F0 maximum of the post-verbal universal quantifier word across the two information structures INFOCUS ($M(318) = 37.85[6.19]$) and UNFOCUS ($M(320) = 39.22[6.3]$). Mean F0 maxima are depicted in Figure 3.

Analyzing the F0 range data, the most parsimonious model contained only VOWEL as a fixed factor, and ITEM and SUBJECT as random factors without random slopes. No main effect was detected either of SCOPE ($\chi^2(1) < .001;\ p = .99$) or of IS ($\chi^2(1) = .33;\ p = .57$), and no interaction was found. Figure 4 shows the mean F0 range of the first vowel of each word in the critical sentences across the four conditions.

[16] Since the initial vowels of words differ from each other, and furthermore, they appear in different prosodic positions and segmental environments, *a priori* it was highly likely that for some of the measured parametric variables the VOWEL factor would have a main effect. This was borne out: in the case of duration and range, VOWEL had a significant main effect. As these effects are not meaningful in the context of our research questions, we do not report them in the statistical analyses presented in the paper. For the same reasons we refrain from performing pairwise comparisons (within each level of VOWEL) if no fixed factor (other than VOWEL) is found to have a significant effect on the dependent variable (although for the sake of prudence we do report any interactions between VOWEL and the other fixed factor(s)).

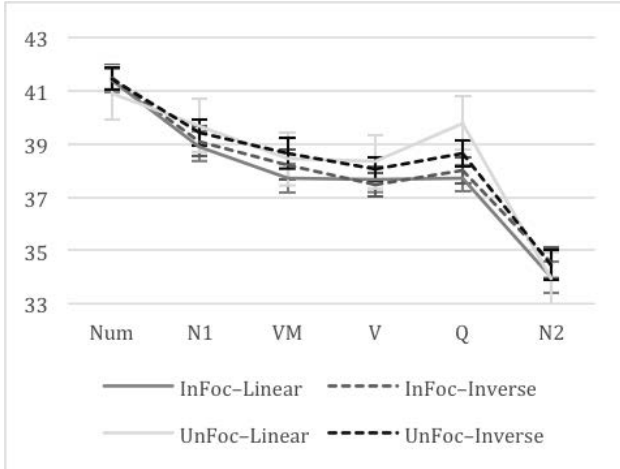

Figure 3: F0 maxima (st) (with SE)

The proportions of falling pitch in vowels were analyzed using logistic regression mixed models. During model selection no significant differences were detected within the VOWELs in the rate of falling realizations either between the two SCOPE readings ($\chi^2(1) = .03;\ p = .85$) or between the two levels of IS ($\chi^2(1) = .30;\ p = .59$). The most parsimonious model lacked both SCOPE and IS as fixed factors; it only included the VOWEL factor, with no random slopes in SUBJECT and ITEM. With regard to the mean F0 slope of vowels with falling pitch, which is depicted in Figure 5, the most parsimonious model excluded both SCOPE and IS as fixed factors, and only contained VOWEL and an interaction between SCOPE and VOWEL, with the SUBJECT random factor having VOWEL as a random slope. No main effect was found either of IS ($\chi^2(1) = .68;\ p = .41$) or of SCOPE ($\chi^2(1) = .01;\ p = .91$). IS and SCOPE showed no interaction. Finally, in the case of duration the most parsimonious model contained only VOWEL as a fixed factor, and VOWEL was also included as a random slope in the SUBJECT random factor, while ITEM was included without random slopes. Neither IS ($\chi^2(1) < .001;\ p = .98$) nor SCOPE ($\chi^2(1) = .02;\ p = .88$) had a significant effect on vowel duration, and no interaction was revealed between the fixed factors. Mean vowel durations are depicted in Figure 6.[17]

[17] We also tested whether the repetition of the stimuli had an effect on the results. The position of each recording in the sequence of repeated recordings was considered as

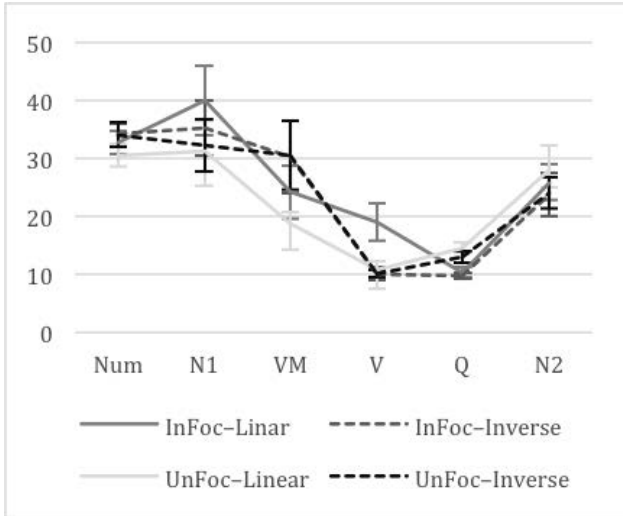

Figure 4: F0 range (Hz) (with SE)

4. Discussion

The foregoing experiment examined the production of linear and inverse scope interpretations in doubly quantified sentences in Hungarian in order to test whether quantifier scope alone systematically affects sentence intonation, in particular, relations of prosodic prominence, in a way that is independent of, or additional to, the prosodic encoding of, information structure. To this end, doubly quantified sentences were placed in different dialogues that served to elicit specific information structural and scope interpretations. In particular, it was varied in topicless sentences whether the numeral of a pre-verbal existential indefinite NP or the quantifier of a post-verbal universally quantified NP functioned as the focus, whose given

a fixed factor (REC) with four levels (= 1st, 2nd, 3rd and 4th recording of the given stimulus). REC was added to the models described in the main text. No main effect of REC or interaction involving REC was found in the measure of F0 maxima, F0 slope and F0 range. A significant main effect of REC ($\chi^2(3) = 4248$; $p < .0001$) was detected in the duration data, but crucially, again without interaction with the other fixed factors, including VOWEL. In particular, the first recording differed from all the other three recordings (1st vs. 2nd: z-ratio = 5.4, $p < .0001$; 1st vs. 3rd: z-ratio = 5.37, $p < .0001$; 1st vs. 4th: z-ratio = 5.18, $p < .0001$), while the latter three did not differ from each other significantly. In short, no effect of repetition was found in our data that is meaningful from the perspective of our research questions.

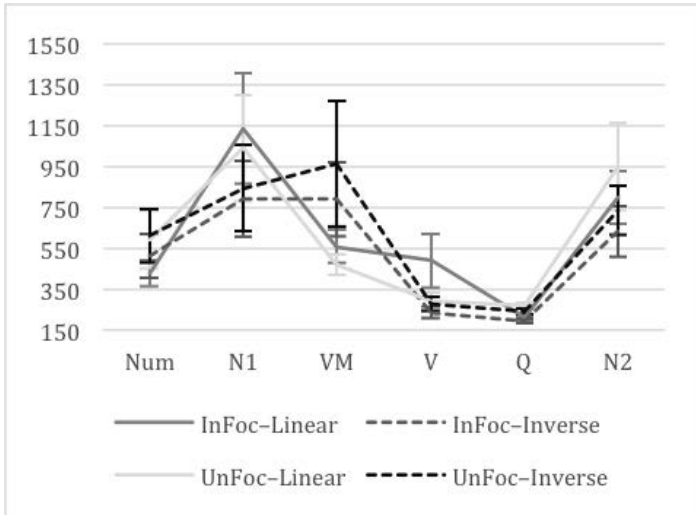

Figure 5: F0 Slope (Hz/s) (with SE)

background was supplied by the rest of the sentence. These two types of information structures were crossed with linear and inverse relative scope interpretations of the two NPs.

With regard to the effect of information structure, it was anticipated that the two information structures would be prosodically distinguished in speech production: in particular, narrow focus on the quantifier/numeral of an NP would boost its phonetic prominence at least in terms of the F0 peak of falling accents, and possibly also in terms of other acoustic parameters that have been claimed to be utilized in prosodic prominence marking in Hungarian. This expectation was borne out in that the mean F0-maximum of the accented vowel of the post-verbal universal quantifier was significantly higher when it was focused than when the focus role was assigned to the pre-verbal scope-bearing NP. The result is in line with earlier results suggesting that the scaling of F0-maximum is an outstanding cue to the prosodic prominence of falling accents in Hungarian (see section 3.2.).

By contrast, scope interpretation was not found either to have any significant effect on any of the investigated acoustic parameters, or to interact with information structure in determining sentence intonation. This outcome suggests that logical scope alone is not expressed in sentence prosody in a way that would go beyond the prosodic realization of information structure.

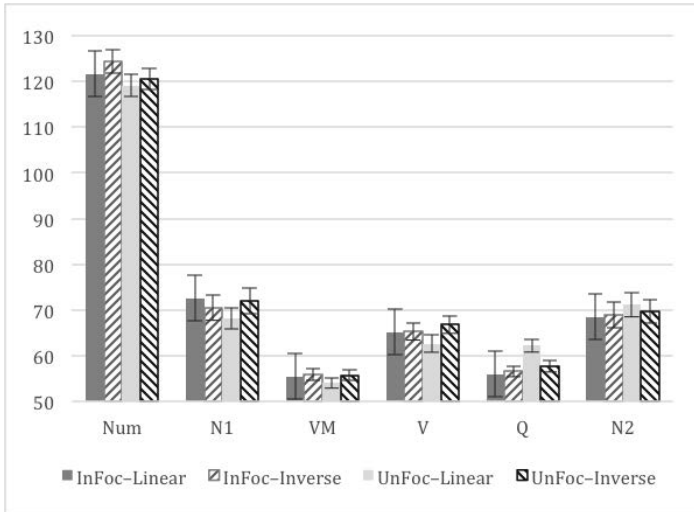

Figure 6: Duration (ms) (with SE)

In general, it is difficult to draw strong conclusions from null hypothesis significance testing if the finding is the lack of an effect. However, this finding of a null effect of scope interpretation is to be juxtaposed to the significant effect displayed by information structure within the same experiment. Furthermore, our results are convergent with Baltazani's (2002a;b) and Gyuris & Jackson's (under review) similar findings in sentence processing.[18] As noted in section 3, these authors investigated doubly quantified sentences in order to explore the potential influence of prosody on scope interpretation in *perception*. Although there are several further differences, beyond the perception versus production perspective adopted, between the design of their experiments and that of ours, the outcomes of their studies also revealed no significant effect of prosodic prominence relations on the scope interpretations assigned.[19]

[18] In a recent study Radó & Bott (accepted) have also found no evidence that contrastive intonation facilitates inverse scope readings in German SVO sentences in an acceptability rating experiment. We thank an anonymous reviewer for pointing us to this work.

[19] The textual stimuli in their perception study were different in various ways from the stimuli used in our experiments. Recall, for instance, that their target sentences had one of the quantified phrases in a pre-verbal position that is unvaryingly associated with a focus role. Furthermore, target sentences were embedded in a monologue

The question arises whether the null effect of scope may be due to the complexity of the experimental task. Namely, it might be that the participants simply failed to adequately discriminate between the two types of target scope readings on the basis of the stimuli they were presented with. While this possibility cannot be categorically excluded, there is ample reason to believe that this was not the case.

First, in relation to the visual stimuli that were used in the experiment, Bott & Radó's (2007) methodological results are of direct relevance. As noted in section 3.1., these authors compared different methods of collecting judgments of scope interpretation in a series of experiments. Their results demonstrated vividly that abstract diagrams similar to the ones employed in both of our experiments, in which connecting lines represent relations between two sets of entities, provide valid and reliable stimuli in sentence–picture verification tasks that require subtle judgments of quantifier scope interpretation.

The visual representation of scope was paired in the experiment with different dialogues. Speaker A's sentences within these dialogues are also directly relevant to the adequacy of the task in eliciting a certain scope reading in the target sentence. Namely, Speaker A's context-setting sentences also served to reinforce the intended scope interpretation of the target sentence. As noted in section 3.1., in critical trials Speaker A's sentences were invariably associated with a surface scope interpretation. Speaker B's corrective target sentence was interpretable as congruent with the context if and only if it was interpreted with scope relations parallel to those in Speaker A's utterance. Thus, the targeted scope interpretation was fixed in each critical trial not only by the visual stimuli but also by the context.

An additional argument bolstering our position that the complexity of the task did not neutralize the distinction between the two targeted scope interpretations comes from another experiment that included the same set of stimuli that formed the critical trials in the present study. That experiment, reported on in Surányi & Turi (2017), involved naturalness judgments: participants had to judge, using a Likert scale, how natural Speaker B's corrective sentences are as an expression of the target meaning depicted by the relevant figure (the one on the right hand side, underneath Speaker B's utterance). A control condition included in this experiment revealed that when Speaker B's sentence had a(n otherwise grammatical) word order that failed to readily license the depicted scope

context, which did not specifically trigger any particular information structure or scope interpretation.

interpretation, judgments dropped dramatically in comparison to the target condition that informational structurally matched it ($p < .001$, Cohen's $d = 1.13$). This indicates clearly that participants correctly accessed the targeted scope interpretation of Speaker B's sentence, as a function of both the context and the associated diagram. Thus we conclude that the absence of a significant effect of scope in the present study cannot be accounted for by assuming that participants failed to access the targeted scope readings due to the complexity of the stimuli.

In view of the foregoing considerations, we feel justified to infer that the null effect of scope revealed by our production experiment very likely reflects a genuine absence of a systematic, grammatically significant influence exerted by quantifier scope interpretation on the investigated aspects of sentence prosody.

It is important to note, finally, that this conclusion should not be taken to exclude the possibility that in some cases distinct information structures may license, or favour, distinct scope interpretations. In such cases any divergence in prosodic realizations that may be associated with scopal differences is an effect of information structure. Indeed, as we suggested in section 2.2., it is highly plausible that precisely this is manifested in all of the cases reviewed in section 2.1.

5. Conclusion

It has been observed in a wide range of languages and constructions that it is possible for differences in scope interpretation to be matched with differences in sentence prosody. Importantly, as information structure is a potential confounding factor in all such cases, as it appears to richly interact both with scope interpretation and with prosodic form. Thus, it is not clear whether quantifier scope itself can be expressed in sentence prosody autonomously of information structure. The present study addressed this question in Hungarian, a language for which it has been claimed that quantifier scope correlates with relative prominence relations in sentence prosody.

A production experiment was performed to explore the potential role of prosody in the expression of logical scope in grammatically scope-ambiguous doubly quantified sentences that contained no syntactically marked topic or focus. The scope reading and the information structural interpretation of target sentences were elicited using a dialogue context and visual stimuli. Two focus structures were crossed with the linear and inverse relative scope interpretations of the two quantified phrases. To our

knowledge, this is the first experiment that has examined the manifestation of quantifier scope in prosodic production using a design in which scope interpretation and information structure were crossed experimentally as independent factors.

While the results confirmed the effect of information structure, the measured acoustic cues of prosodic prominence were not found to exhibit any significant differences across the two scope conditions of linear and inverse scope interpretation, nor did they reveal any significant interaction of scope and information structure. These outcomes are argued to corroborate the position that quantifier scope itself has no grammatically significant effect on the investigated aspects of prosody in sentence production in Hungarian.

While we take our results to be suggestive of the absence of a grammatical effect of scope on prosody in sentence production, further replications of this finding, using a variety of methods, are necessary in order for this conclusion to become firmly established. In order to broaden the empirical basis of this claim, especially valuable would be further studies probing into phonetic variables different to those investigated in this paper. Although we examined the main parameters that we expected to be potentially affected based on prior literature, these parameters might be considered for larger phonological units than in this paper (e.g., for initial syllables rather than initial vowels), and phonetic cues not analyzed here (e.g., relative intensity, vowel quality) may also be fruitfully explored.

While the present results cast doubt on the view that quantifier scope can be directly encoded in sentence intonation, they are compatible with the restrictive view, instead, that logical scope is reflected in prosody only in cases in which scope interpretation is a free rider on information structure (a possibility raised for all the cases reviewed in section 2). If correct, this view entails that prosodic correlates of logical scope in themselves do not pose an issue for the Y-model of the grammar, which eschews any direct mapping between the interface components SEM and PHON.

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