Processing relative clauses by Hungarian typically developing children

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Abstract

Hungarian is a language with morphological case marking and relatively free word order. These typological characteristics make it a good ground for testing the crosslinguistic validity of theories on processing sentences with relative clauses. Our study focussed on effects of structural factors and processing capacity. We tested 43 typically developing children in two age groups (ages of 4;11–7;2 and 8;2–11;4) in an act-out task. Differences in comprehension difficulty between different word order patterns and different head function relations were observed independently of each other. The structural properties causing difficulties in comprehension were interruption of main clauses, greater distance between the verb and its arguments, accusative case of relative pronouns, and SO head function relations. Importantly, analyses of associations between working memory and sentence comprehension revealed that structural factors made processing difficult by burdening components of working memory. These results support processing accounts of sentence comprehension in a language typologically different from English.

Processing relative clauses is one of the thematic priorities in psycholinguistics. The processing and production of sentences with multiple propositions is a well-suited testing ground for studying the identification and maintenance of thematic roles and their relationships throughout the sentence. There is a good body of results on the topic in English, serving as a basis for different theoretical models on the processing of relative clauses (e. g. Gibson 1998, 2000; MacWhinney, 2000; Lewis et al, 2006; Reali and Christiansen, 2007). The validity of these assumptions for typologically different languages like Hungarian has not been tested yet, though. Experimental research on several languages shows that sentence processing may involve different strategies or different factors in different languages (MacWhinney, 1987; Pléh, 1998; Slobin, 1985). The aim of the present study is to test whether the models based on English are able to explain differences in the processing difficulty of different relative clause structures in Hungarian as well. Examining processing relative clause structures in Hungarian provides an opportunity to test linguistic effects that are not available in typologically different languages like English: 1) being able to vary word order patterns and grammatical functions independently allows us to examine their effects separately, 2) having case-marked relative pronouns makes it possible to test the effect of local cues (i.e. morphological marking) on processing of relative clauses.

As the processing models differ with respect to the role they attribute to working memory load in processing difficulties, we chose to test children in two age groups beyond the bulk of syntax acquisition but not yet at the adult level of processing capacity. By examining children in two different age groups, we hope to extend testing predictions of processing accounts to populations where processing capacity is not yet at ceiling, and this way, testing hopefully reveals effects that are potentially hidden by adult capacities. Choosing such groups also allows testing correspondences between individual differences in working memory capacity and comprehension of different structures.

In what follows, we first give a summary of relevant aspects of Hungarian syntax following É. Kiss (2002), highlighting psycholinguistically important differences relative to English. Then we review the major findings concerning relative clause processing and introduce different models put forward for English relative constructions, together with the formulation of their predictions for Hungarian. We present results from a sentence comprehension task with typically developing Hungarian children and finally we summarize the conclusions for the processing theories.

An outline of Hungarian syntax

Hungarian is generally described as a language with free word order, because grammatical functions like subject, object etc. are morphologically marked and not linked to specific structural positions in the sentence. Thus, phrases in a simple transitive sentence consisting of a verb with two arguments, e.g. *várja* 'waits for', *Péter* 'Péter' and *Sárit* 'Sarah-ACC' may take all the combinatorically possible arrangements to yield a grammatical sentence (1). Note that the subject is morphologically unmarked while the object is case-marked by the accusative suffix–*t*.

(1)   SVO: *Péter várja Sárit.*   SOV: *Péter Sárit várja.*

        OVS: *Sárit várja Péter.*   OSV: *Sárit Péter várja.*

        VOS: *Várja Sárit Péter.*   VSO: *Várja Péter Sárit.*

However, although the events described by these sentences are the same (Péter is waiting for Sarah), these word-order combinations are used in different contexts and show slight pragmatic differences. Structural positions do represent certain logical-semantic operators, among which topic and focus are of greatest importance. Hungarian sentences may be divided into a topic and a predicate part. The topic part identifies a participant of the event explicated in the predicate part. Although the topic constituent always precedes the predicate, the topic and subject functions are independent of each other, that is, any participant of an event can be topicalised. Thus, in (2a) it is the subject (or agent) and in (2b) it is the object (or patient) that takes the sentence-first topic-position. (Since in English topic and grammatical subject are linked, (2b) is translated as a passive sentence, while in Hungarian, it only differs from (2a) in its word order.)

(2a)   [TOP Péter] [PRED fel hívta Sárit]

        Peter-NOM   up called Sarah-ACC

        'Peter called Sarah up.'

(2b)   [TOP Sárit] [PRED fel hívta Péter]

        Sarah-ACC   up called Peter-NOM

        'Sarah was called up by Peter.'

The central part of the predicate is the verb. Hungarian verbs frequently have verb modifiers (prefixes) which modify the meaning of the verb, e.g. express aspect or directions for movement-related verbs. In neutral sentences like (2a, b) verb modifiers directly precede the

verb. However, in sentences with focussed constituents, which are specific constructions, one of the arguments occupies the preverbal position, carries prominent phonological stress and involves the movement of the verbal modifier to a postverbal position. Focus constructions express restricted reference of the predicate exclusively to the specific argument which is in focus. So for (3a) the only person that Peter called was Sarah, and for (3b) the only person who called Sarah was Peter (arguments in focus appear in small capitals).

(3a)   [TOP Péter]   [PRED SÁRIT   hívta fel]

         Peter-NOM   Sarah-ACC called up

     'As for Peter, it was Sarah that he called.'

(3b)   [TOP Sárit]   [PRED PÉTER   hívta fel]

         Sarah-ACC   Peter-NOM called up

     'As for Sarah, it was Peter that she was called by.'

Just like topicalisation, any of the arguments can be focussed, e.g. the object in (3a) and the subject in (3b). Thus, focussing has three structural features: (i) pre-verbal position, (ii) primary phonological stress, and (iii) movement of the verbal prefix.

Sentences with relative clauses

Relative clauses (henceforth, RCs) are sentential complements usually attached to one of the NPs in the main clause (this noun phrase is usually called the head of the RC), either restricting its reference or supplying further information on it. The types of complex sentences with RCs are differentiated by the grammatical function of the head in the main clause and the positions of the gap in the RC. In English, the SS-type sentence contains a RC attached to the subject of the main clause, in which the subject is gapped/deleted. The same main clause structure with a gap in the object position in the RC is called SO, and so on, as shown in the following examples, taken from Diessel and Tomasello (2005).

(4a) SS

    The dog [that ___ jumps over the pig] bumps into the lion.

(4b) SO

    The lion [that the horse bumps into ___] jumps over the giraffe.

(4c) OS

    The pig bumps into the horse [that ___ jumps over the giraffe].

(4d) OO

    The dog stands on the horse [that the giraffe jumps over ___].

These structures have several psycholinguistically relevant features which are quite different in Hungarian relatives. First, in English, there is no specific lexical item that would help recognize the RC structure (pronouns like *who* and *that* appear in other functions as well, and they are not overt in every RC) and there is no element that would clarify the function of the head in the RC. In contrast, Hungarian RCs contain specific elements that are fully reliable and available markers of a RC structure. These relative pronouns cannot be omitted and they invariantly occupy the initial position of the RC. They convey information about their referents regarding grammatical function and whether it is human or not. Humanness of the referent is marked by different relative pronouns in RCs attached to an argument representing a human versus a non-human referent. The pronoun for human referents is *aki*, and those for non-humans are *ami, amely* or *amelyik*. Applying *aki* for animals or objects is permitted in special contexts like tales, but using *ami* for people is considered

ungrammatical, as examples in (5a, b, c) show (REL marks the relative pronoun. Case is also marked when relevant: e.g. REL.ACC is relative pronoun with a suffix marking accusative case).

(5a) A fiú,   aki/*ami le   esett...

   The boy   REL   down fell...

   'The boy who fell…'

(5b) A kutya, aki/ami le   esett...

   The dog   REL   down fell…

   'The dog who fell…'

(5c) A kő,   ??aki/ami le   esett...

   The stone REL   down fell

   'The stone that fell…'

The second and more important difference concerns identification of constituent roles. In contrast to English, there is no motivation for assuming gaps in Hungarian RCs. First, both subjects and objects are omissible in Hungarian, so a sentence consisting of only a predicate is fully grammatical (the reference of the subject and the object is clarified by the verbal suffixes and the context (6).

(6) Látom.

   See-PresIndef1st Sg

   'I see her/him/it.'

Second, free order of clausal constituents (shown in (1)) makes any hypothetical position of gaps (like preverbal position of subject gaps and postverbal position of object gaps in English) very difficult to justify. Considering processing models that calculate exact distances of syntactic integration it is crucial to have valid hypotheses concerning syntactic positions, therefore in our analysis of Hungarian RCs we do not operate with gaps in the structures. Instead of linking the gap to the wh-filler seen in English, the function of the relative pronoun in Hungarian RCs is identified locally by case marking suffixes. Similarly to German and French, Hungarian relative pronouns can take any of the nominal case markers; this way the function of the head is made clear at the first word of the RC. For these reasons in the following we will replace the terms 'RCs with subject/object gaps' with 'RCs with nominative/accusative relative pronouns'. Examples with nominative, accusative and dative relative pronouns are given in (7a–c), respectively.

(7a) A lány, aki   sírt…

   The girl REL.NOM   cried

   'The girl who cried…'

(7b) A lány, akit   láttam…

   The girl REL.ACC   saw-1stSg

   'The girl whom I saw…'

(7c) A lány, akinek   írtam…

   The girl REL.DAT   wrote-1stSg

   'The girl that I wrote (a letter) to…'

Another important point is that since relative pronouns are case-marked they constrain the type of constituents that might and should follow in the sentence. For instance, a relative

pronoun with an accusative case marker (7b) requires a transitive verb and a subject (which is only optionally overt), which is more than what would be predicted by a nominative pronoun (which can be followed by a verb and an NP in any grammatical function, or no other NPs). From the processing point of view, the relevant properties of Hungarian relative pronouns are the following: (i) their function is clarified morphologically, by the case marking suffixes, (ii) their obligatory position is clause-initial, and (iii) they constrain syntactic predictions more than English complementizers.

Another important difference between English and Hungarian concerns the structural relationship between the function of the head in the main clause and the embedding position of the RC. Because of the strict word order, English S-headed relatives always interrupt the main clause while O-headed ones never do so (see (4a, b) versus (4c, d)). As a consequence, the effect of head functions and interruption of the main clause cannot be investigated independently. In Hungarian, however, due to the variable word order, the embedding position of the RC and the function of the head may be independently varied. Examples for S-headed RCs that don't interrupt the main clause and O-headed ones that do, both unattested in English, are given in (8a) and (8b), respectively. There is also a special construction in which the focussing of the head preceded by an index pronoun (IND) in the main clause allows right-extraposition of the RC so that it can appear further away from its head as (8c) shows. Note that Hungarian NPs with index pronouns always include an article, e. g. 'az a kutya' (IND the dog, 'that dog'), and that case is always marked on the index pronouns as well as on the nouns, e. g. 'azt a kutyát' (IND.ACC the dog-ACC, 'that dog' as an object).

(8a) A   kacsát   meg ette   a kutya,   amit   tegnap   vettem.

The duck-ACC   up   ate-3rdSg the dog-NOM REL.ACC yesterday bought-1stSg

'The dog that I bought yesterday ate the duck.'

(8b) A kacsát,   amit   tegnap vettem,   meg ette   a kutya.

The duck-ACC REL-ACC   yesterday bought-1stSg up ate-3rdSg the dog-NOM

'The dog ate the duck that I bought yesterday.'

(8c) Azt a kacsát   ette   meg a kutya,   amit   tegnap vettem.

IND the duck-ACC ate-3rdSg up the dog-NOM REL-ACC yesterday bought-1stSg

'It was the duck I bought yesterday that the dog ate.'

The function of the head, the position of the gap, and the interruption of the main clause are important factors of processing sentences with RCs in English. Hungarian differs from English along all the above dimensions, which are potential influences on processing and this way, are important in crosslinguistic testing of theories of sentence processing. In the next section, we present processing hypotheses based on studies of English, together with their predictions for Hungarian.

Processing theories and their application to Hungarian

It is a widely known fact that the processing of certain types of RCs is more difficult than others. Structural differences causing processing problems have been found in a lot of studies investigating children and adults with typical and atypical language abilities across languages. The most robust evidence reveals that (i) sentences with RCs that interrupt the main clause are more difficult to understand than sentences with non-interrupting RCs (Bever, 1970; Tavakolian, 1981; deVilliers et al, 1979 for children; Chomsky and Miller, 1963; Gibson, 1998; Lewis, 1996 for adults), and (ii) RCs with an object gap are more difficult than those with a subject gap (for adults, see Holmes & O'Regan, 1981; King & Just, 1991; Gibson, 1998, 2000; Reali and Christiansen, 2007 for English; Schriefers,

Friederici & Kuehn, 1995 for German; Carminati et al, 2006 for Italian; for children, see
Friedmann and Novogrodsky, 2004 for Hebrew; Friedmann and Costa, 2010 for Hebrew and
Portugese; Adani et al, 2010 for Italian; Stavrakaki, 2001 for Greek, Diessel and Tomasello,
2005 for German). Examples are given below: a sentence with the RC following the main
clause (9a) is easier to understand than the one with the RC interrupting the main clause
(9b). (9b) is in turn easier than (9c) since the relative in (9b) contains a subject gap, while
the one in (9c) contains an object gap.

(9a) OS: The horse hit the sheep that __ kissed the duck.

(9b) SS: The horse that __ hit the sheep kissed the duck.

(9c) SO: The sheep that the horse hit __ kissed the duck.

Different groups of hypotheses and theories have been proposed to explain the difference in
processing difficulty between the above structures. The theoretical emphasis in these
approaches is quite different; there are models that argue for an effect of more complex
thematic representations (Sheldon, 1974; MacWhinney, 2000), a greater burden on working
memory (Slobin and Bever, 1982; Pléh, 1998; Gibson, 1998, 2000), interferences between
sentence parts during processing (Lewis and Vasishth, 2005; Lewis et al, 2006) or different
frequency of occurrence of different sentence types (Bever, 1970; Mitchell, Cuetos, Corley,
& Brysbaert, 1995; Tabor, Juliano, & Tanenhaus, 1997; Reali and Christiansen 2007).

One of the first accounts of comprehension differences between RC structures in child
language in terms of complexity of thematic representations was Sheldon's parallel-
functions hypothesis (Sheldon, 1974). She claimed that sentences with RCs are easier to
process when the function of the head is the same in both clauses, e.g. SS and OO types are
easier than OS and SO types. Complexes with parallel thematic functions can be assigned a
simpler thematic representation during comprehension, while if the functions differ in the
two clauses, the heads have to be assigned two different thematic roles, which increases
complexity. However, more recent models suggest that comprehension difficulties do not
arise from non-parallel functions per se; difficulties with assigning different thematic roles
to the constituents are more related to the different word order patterns correlated with
different head functions.

The perspective-shift account of MacWhinney (2000) claims that in left-to-right processing
of the sentence, the difficulty is caused by a shift in perspective (changing the referent that
determines the perspective of the interpretation of the sentence). In English, the perspective
of a clause is determined by the subject. As a consequence, for the comprehension of an SS
type sentence no perspective shift is required, as both clauses have the perspective of the
main clause subject. The OS and OO types are more problematic, as the subject of the
embedded clause differs from that of the main clause, so the perspective needs to be shifted
at the beginning of the embedded clause. In processing the SO type, interruption and
function mismatch require two shifts: first from main clause subject to the subject of the
embedded clause, then, in processing the rest of the main clause, back to the main clause
subject (see examples in (4)). For English, MacWhinney's perspective-shift hypothesis
predicts an order of difficulty similar to Sheldon's (since perspective and subject function
are linked), but with a difference between OS and SO types: SS < OO, OS < SO
(MacWhinney & Pléh, 1988). In Hungarian, however, perspective is not determined by the
subject, but mostly by the topic of the clause–that is, by the constituent marked as the theme
in the logical structure of the sentence, which is structurally the constituent in sentence
initial, stressed position. If there is no topic, it is the focussed constituent that determines
perspective–the one appearing in the prominent, preverbal position bearing primary
phonological stress. As the topic position of the RC is always occupied by the relative
pronoun which has the same referent as the head, the perspective of the RC is always the

same as the head's. This way, if the head of the RC is in topic position in the main clause, there is no need for a perspective shift in processing, and this is true for all the four RC construction types. So in Hungarian the processing difficulty of sentence types according to their head functions is in principle the same. Differences are predicted based on the position of the head in the main clause, though, i.e. whether it occupies a topic-, or at least a sentence initial focus position. If so, following the above arguments, there is no perspective shift in (10a). If, on the other hand, the head is preceded by another NP in the main clause like in (10b), a perspective shift is necessary not later than at the processing of the relative pronoun at the beginning of the RC, and this is true for all sentence types (examples in 10a–b are of the SS type).

(10a)   Az a kutya,   aki   kergette a kecskét, meg rúgta a malacot.

        IND the dog-NOM REL-NOM chased the goat-ACC up kicked the pig-ACC

        'The dog who chased the goat kicked the pig.'

(10b)   A malacot   az   a kutya,   aki   kergette a kecskét,   meg rúgta.

        the pig-ACC IND the dog-NOM   REL-NOM chased the goat-ACC up kicked

        'The dog who chased the goat kicked the pig.'

Based on these arguments, the prediction of the perspective-shift hypothesis for Hungarian is that processing of RCs with a sentence-initial head is easier than those with a non-sentence-initial head, regardless of their type. Since two perspective shifts are never required, differences are expected to be less pronounced.

Other approaches based on working memory models are also concerned with word order patterns but they emphasize the energy costs of storage and integration of sentential constituents during sentence processing. Slobin and Bever (1982) proposed that based on a processing strategy trying to avoid interrupted structures, processing of interrupted clauses is more difficult than that of uninterrupted clauses, because the main clause cannot be exhaustively processed before the interpretation of the embedded clause begins. As English subject-headed RCs always, while object-headed RCs never interrupt the main clause, their prediction for the order of difficulty in English is SS, SO < OS, OO. A version of this hypothesis suggesting graduality has been put forward by Pléh (1998), claiming that processing difficulty of interrupted structures is related to greater demands on working memory capacity. In clauses corresponding to typical English subject-headed structures (SS, SO), the sentence-initial NP is not linked to the verb and its thematic role remains unclear until the end of the sentence. This presents a greater demand on working memory, since while memory traces of constituents with an already identified thematic role might fade, the unidentified NP has to be kept active, and at the same time, the embedded clause has to be processed as well.

More recently, the effect of memory load has been formulated thouroughly in the dependency locality theory (DLT) of Gibson (1998, 2000) using exact metrics for calculating memory costs of storage and syntactic integration. The DLT claims that the syntactic and semantic features of each word are encoded during comprehension and syntactic predictions are generated based on this information, e.g. a sentence-initial NP triggers a prediction for a predicate, Any syntactic prediction has to be stored in working memory until the constituent with the required encoded features is processed later in the sentence. At that point, the encoded features of the predicted word are integrated with the previous syntactic prediction. As both these processes are costly, two kinds of energy consuming components are differentiated in DLT: (i) memory costs of storing the syntactic predictions and (ii) costs of syntactic integrations. Roughly speaking, the storage cost at any given point during processing is determined by the number of syntactic predictions to be

stored at a time, while the integration costs are determined by the number of newly introduced discourse referents (nouns and verbs) and the distance between the constituents to be integrated (measured by the number of intervening words). It is also assumed that the two kinds of processing rely on a common resource pool. This model accounts for the processing difficulties of the interrupted main clause shown in (9b) compared to (9a) in terms of the greater costs of storing temporally incomplete syntactic representations together with their predictions. As for the processing difficulties of relatives with an object gap (as the one in 9c) compared to those with a subject gap (9b), the DLT suggests that the object gap and the wh-filler has to be integrated across a greater distance, due to the intervening verb and subject NP.

Adapting this account for Hungarian is promising on the one hand but has its limitations on the other. First, as we mentioned above, Hungarian RCs are differentiated not by the position of the gap but by the case of the relative pronoun. As relative pronouns always occupy the clause-initial position and their case can be locally identified, there are no constant distance differences between the syntactic integration of nominative and accusative relative pronouns and the embedded verb. For this reason, since the DLT is only concerned with word order differences, it does not predict any processing difference between relatives with nominative and accusative pronouns (that is, between subject and object relatives). As opposed to this limitation, the variable word order of main clauses makes Hungarian a good testing ground for other predictions of the DLT. Compared to a main clause with a nested RC (11a) that is similar to typical SS relatives in English, there are possible word order patterns in Hungarian that would either be predicted being more or less difficult to process by the DLT, independently of grammatical functions. In case of a main clause with NNV word order (11b), the working memory demands get greater as there are two NPs whose syntactic integration with the sentence-final main verb is very costly due to the large number of intervening discourse referents. In contrast, the processing of the non-interrupted version of the same sentence is almost free of memory charge, as the syntactic predictions of each word is satisfied almost immediately by the following phrase, so neither significant memory cost nor integration cost is present (11c). Note that all examples in (11a–c) are of the SS type.

(11a) Az a kutya,   aki   kergette a kecskét, meg rúgta a malacot.

    IND the dog-NOM REL-NOM chased the goat-ACC up   kicked the pig-ACC

    'The dog who chased the goat kicked the pig.'

(11b) A malacot   az a kutya,   aki   kergette a kecskét,   meg rúgta.

    the pig-ACC IND the dog-NOM   REL-NOM chased the goat-ACC   up kicked

    'The dog who chased the goat kicked the pig.'

(11c) Az a   kutya   rúgta meg a malacot, aki   kergette a kecskét.

    IND the dog-NOM kicked up the pig-ACC REL-ACC chased the goat-ACC

    'The dog who chased the goat kicked the pig.'

In sum, comprehension models based on working memory costs predict the processing difficulty being greater for relatives that interrupt the main clauses proportional to the number of sentence-initial NPs to be integrated with the final verb (11c<11a<11b).

As these hypotheses explicitly attribute difficulties with certain syntactic structures to extra working memory load, individual differences between children in working memory capacity might be relevant for their evaluation. If it is indeed difficult to process word orders in which arguments are at a distance from the sentence-final verb as a consequence of a greater burden of working memory resources, then we should observe greater difficulties with these

structures in the performance of children with lower working memory capacity. In contrast, we should not find any effect of individual levels of working memory capacity for structures that are assumed to be less costly in terms of processing.

Another memory-based sentence processing theory adopts a different view of memory and processing mechanisms (Lewis and Vasishth, 2005; Lewis, 2006). Cue-based or interference theories claim that there is no active working memory storage of syntactic predictions and the main processing mechanism is the cue-based retrieval of syntactic information encoded earlier. In such a model, earlier syntactic predictions fade away quickly and can only be kept active by successive retrievals by words processed later. Interference effects can be present at the encoding or the retrieval phase. Explaining the processing difficulty of object relatives, Lewis and Vasishth (2005) argue that in these cases representations for subjects of both the main and the embedded clauses are accessed before either noun phrase could be integrated with their corresponding predicate. As their syntactic predictions are very similar, they interfere, and the interference causes difficulties during integration. If we only consider syntactic features that interfere with each other, then interference theories do not predict processing differences between the structures shown in (11a–c), as the function of Hungarian NPs is always clarified locally by the case markers preventing interference between the first two NPs in (11b). However, interference might also arise from semantic similarity, which is also known to cause interference in the encoding of nouns (Gordon et al., 2002). This way, semantically similar nouns in main clauses with NNV word order (as opposed to NVN word order) as in (11b) might interfere with each other proactively during encoding. If specific difficulties are observed with the assignment of thematic roles in main clauses with NNV word order compared to those with NVN word order, the interference account would get support from Hungarian data as well.

According to experience-based accounts, difficulty of processing of different word order patterns is greatly influenced by their frequency of occurrence (Bever, 1970; Mitchell, Cuetos, Corley, & Brysbaert, 1995; Tabor, Juliano, & Tanenhaus, 1997; Reali and Christiansen, 2007). Bever's (1970) canonical forms hypothesis suggests that the similarity of word orders to word orders of canonical simple sentences is crucial. He claims that as in English simple sentences the NVN schema is a lot more frequent than the NNV schema, the processing of NVN clauses is easier than that of NNV word orders (the latter one is never well-formed in an English main clause). This assumption predicts the SS, OS < OO, SO order of difficulty for English. In a sentence repetition study with children, Diessel and Tomasello (2005) found response patterns in concert with this hypothesis for English, but not in German, leading them to argue for a modification of Bever's hypothesis claiming that it is the match between a sentence-initial NP and the agent that makes processing easier, presumably based on the frequent co-occurrence of these two factors. In Hungarian, NVN and NNV word orders are both well-formed and typical in simple sentences, but there is no data available on their frequency distributions, so one can not formulate exact frequency-based predictions for word order patterns. However, two previous studies suggest a preference for sentences with an initial subject NP in Hungarian too. Pléh (1981) studied comprehension of simple sentences by small children in an act-out task and found that comprehension performance was better for sentences with the subject preceding the object. A tendency to interpret the first NP as agent regardless of the accusative case marker was also observed, similarly to the results of Diessel and Tomasello (2005). Second, the preference for subject-first sentences was revealed in a previous study on RC processing in Hungarian. Pléh and MacWhinney (1988) studied comprehension of several structures in adults in an online reading task. They found that main clause word orders where the subject preceded the object were easier, as were RC heads in sentence initial position. The order of difficulty of processing was OO < OS < SS < SO in their study, so processing of RCs attached to the main clause object were easier than those attached to the main clause subject,

regardless of word order. Interruption of the main clause did not pose a difficulty in itself, and focussing the head in the RC did not affect comprehension either (MacWhinney & Pléh, 1988). In sum, although there is no corpus-based frequency counts available to support hypotheses concerning preferences for word order patterns, previous studies provide a firm basis for expecting easier comprehension of sentences with the subject preceding the object. As in Hungarian all the possible constituent orders are grammatical, such a preference could only be attributed to differences in frequency of occurrence. Although no data is available on frequency distributions of different word orders, we made a frequency count of relative pronouns with different case markers available in the Hungarian Webcorpus (Hálacsy et al., 2004; Kornai et al., 2006), showing that the nominative form 'aki' is by an order of magnitude more frequent than the accusative form 'akit'; while frequency differences are smaller for relative pronouns for non-human referents, occurances of nominative forms still dominate (see Table 1).

Based on the results of Reali and Christiansen (2007), who showed that differences in self-paced reading times of pronominal object/subject RCs by adults reflected the pattern of frequency distribution revealed by an independent corpus analysis, we might expect that RCs with accusative relative pronouns would be more difficult to process than those with the highly frequent nominative relative pronouns.

The above theories and results lead to the formulation of the following hypotheses for the comprehension of Hungarian relative structures. For the sake of clarity, predictions for word order patterns of (i–iii), grammatical functions (iv–v) and for the interaction between these domains (vi) are listed separately. Since in Hungarian word order patterns and grammatical functions can be varied independently of each other, differences along these dimensions are of particular interest as they might allow us to disentangle linguistic factors that are intertwined in English.

i. Non-interrupted main clauses are easier to process than interrupted ones (Slobin and Bever, 1982; Gibson, 1998, 2000).

ii. Increasing the number of NPs preceding the verb makes comprehension more difficult, i.e., main clauses with NNV word orders are more difficult than those with NVN. This is predicted by several theories, but with slight differences. Dependency locality theory predicts that more NPs stacking up in the main clause pose difficulties only when they are separated from the predicate by an interrupting RC as in (11b) and that this structure is more difficult than any other word orders with a single RC due to the costly integration between the two sentence-initial NPs and the final main verb (e. g. 11a, c) (Gibson, 1998, 2000). In contrast, the perspective-shift theory predicts less pronounced difficulties for main clauses with NNV word order with the RC attached to the second NP due to a single perspective shift during left-to-right processing, compared to those with the RC attached to the sentence-initial NP, regardless of the interruption of the main clause (MacWhinney, 2000; Pléh and MacWhinney, 1988). Third, according to the interference theory encoding interference between semantically similar subsequent NPs might also cause difficulties with the assignment of thematic roles in main clauses with NNV word order (Lewis et al, 2006).

iii. Interrupted main clauses with two NPs separated from their predicate pose extraordinary processing difficulty for children with lower working memory capacities. In contrast, there is no effect of individual levels of working memory capacity on structures that are claimed to be less costly in terms of processing by the DLT, that is, sentences with non-interrupted and/or NVN main clauses (Gibson, 1998, 2000).

iv. Object relatives, that is, RCs with accusative relative pronouns are more difficult than subject relatives, i. e. those with nominative relative pronouns, as they are less frequent in the language. This prediction is based on frequency differences in corpus data, which, according to experience-based approaches, influences comprehension ((Bever, 1970; Mitchell, Cuetos, Corley, & Brysbaert, 1995; Tabor, Juliano, & Tanenhaus, 1997; Reali and Christiansen, 2007).

v. Processing of RCs attached to the main clause object are easier than those attached to the main clause subject, regardless of word order–a prediction based in previous results on Hungarian RC processing (Pléh and MacWhinney, 1988).

vi. Main clauses with the subject preceding the object (S-O order) are easier than the reverse (O-S) pattern (based on previous results in Hungarian; Pléh and MacWhinney, 1988).

Method

Test materials

To test the above hypotheses, we compiled a test battery containing sentences with all possible combinations of the following four experimental factors:

- The function of the relative head in the main clause (S or O)

- The case of the relative pronoun (nominative or accusative)

- Position of the head in the main clause (sentence-initial or not)

- Position of the RC (interrupting or non-interrupting)

The four possible combinations of the first two factors are referred to as SS, SO, OS and OO types of complexes with RCs, and the four combinations of the latter two factors combine into the word order patterns relevant to the above hypotheses, that is, interrupting relatives attached to a sentence-initial (N-RC-NV) or a non-initial head (NN-RC-V), and non-interrupting relatives attached to a sentence-initial (NVN-RC) or a non-initial head (NNV-RC).

The combination of the four factors, with two values for each, results in $2\times2\times2\times2=16$ sentence types, shown in Table 2. The test battery contained 6 sentences in each type, yielding 96 sentences altogether. As it was mentioned above, the head of the main clause in sentences with non-interrupting RCs occupies focus position, so a pragmatically more appropriate English translation of these sentences would be similar to the one given in (8c). However, we did not include this aspect in the translations in Table 2, so that the English translation would reflect the structure of the Hungarian sentence better.

We controlled several semantic, syntactic and performance factors in the linguistic material. Sentence length varied between 18–20 syllables. Each sentence was reversible and restrictive concerning its thematic relations, and the participants of the described actions were always animals. The relative pronouns were uniformly *aki/akit* 'who/whom', which is common in children's stories with animals. Word order of the RCs was always relative pronoun–verb–noun phrase regardless of case, and the head of RCs was always an NP containing an index pronoun e.g. *az a kutya* 'that dog'. Both main and RCs were transitive constructions containing a subject, verb and an object. The head of non-interrupting RCs was focussed in the main clause, while the head of interrupting RCs was not.

Procedure

Comprehension of sentences was tested in an act-out task. Children were presented with a standard display of toy animals: in the center, facing the child, there was a big goat chasing a small dog, next to them a big dog chasing a small goat, and all the other animals were scattered around these two pairs. They were instructed to use them to act out the sentences spoken by the examiner. Note that the arrangements ensured that there was both a goat that was a chaser and one that was chased, and the same was true for the dogs. Following Hamburger and Crain (1982)'s observations, we created a naturalistic context in that the restrictive RCs always required a choice between two animals for identifying the agent and the patient. All actions were transitive (kiss, tickle, bite, kick, push, stroke); one of the participants in the sentence was always one member of the two dog-goat pairs (big goat-little dog, big dog-little goat), the other participant was some other animal: the main clause subject or object was always a dog or a goat, and the RC constrained whether, from the two potential animals on the table, the animal in question was chasing or was being chased. An example of an experimental sentence and its expected interpretation together with the possible errors is given in (12) below.

We coded the actions corresponding to sentences on the answer sheet. An answer was correct if in acting out the sentence, the identification of roles for both participants–agent and patient - was correct (even when the action itself was not, although this was also marked on the answer sheet). In analyzing the errors, we were curious whether wrong identification of the relative head is typically a lexical error or an error of role assignment, i.e. whether children primarily get the kind of the animal or rather its thematic role in the action wrong. We also wanted to test whether this pattern is influenced by the function (subject or object) of the head. Examples for different error types are given in (12).

(12) Az a kutya,   akit   kergetett a kecske,   meg harapta a majmot.

      IND the dog-NOM REL.ACC chased   the goat-NOM VM bit   the monkey-ACC

      'The dog whom the goat chased bit the monkey.'

Expected interpretation: the chased dog bites the monkey

Errors in identifying the RC head:

- Role mismatch only: chasing dog instead of chased dog

- Lexical mismatch only: chased goat instead of chased dog

- Role and lexical mismatch: chasing goat instead of chased dog

These three types of errors were counted separately for sentences with different head functions (subject versus object). It seemed necessary for the evaluation of the hypotheses to count the number of errors involving subject-object inversions in the interpretation of main clause subjects and objects, by sentence type. An error was categorized as subject-object inversion if both subject and object of the main clause were correctly identified but their roles were inverted. This category also covered occasional role or lexical mismatches (or both) in only one of the constituents (subject or object), that is, additional errors caused by the misinterpretation of the RC.

Participants

43 children participated in the study from 3 preschools and 2 schools in Budapest. Participants were divided into two age groups: children (25) between 4;11–7;2 belonged to the younger group; the age range of the older group was 8;2–11;4 (18 children). We also administered the task to a control group of adults which consisted of 17 university students

between 19;1–22;8 years. This ensured that the performance level of the children is distinguishable from that of adults, and made comparisons and correlations between sentence comprehension and working memory capacities possible. Details of data for the groups are shown in Table 3.

Working memory measures were available for 34 out of the 43 children. We administered three tasks measuring different combinations of components of the working memory system; in their interpretation, we will rely on Baddeley's model of working memory (Baddeley, 1986; 2003). The capacity of the phonological loop was measured by nonword repetition and digit span tasks, while the central executive (and the phonological loop) was tested by a backward digit span task.

All three tasks are parts of the standard Hungarian inventory developed for measuring working memory by Racsmány and colleagues (2005). Immediate repetition of digit sequences or nonwords involves processing and reconstruction of certain lexical or phonological items and their order, so these tasks require auditive processing, short term storage and encoding of information. Note that quality of the stimulus material is an important factor: accuracy of phonological discrimination and reproduction is essential for the processing of nonwords, while it is not crucial for digits since the latter are frequently occurring lexical items that are easily recognizable using lexical top-down information. Reversed repetition of digits requires an additional sequential transformation, which is claimed to be the function of the central executive in Baddeley's model, similarly to other types of information re-structuring processes. Thus, the efficiency of backward repetition of digits is determined by the ability to store and convert a chronological sequence of auditive stimuli.

Results

Analysis of correct responses

We analysed percentages of correct responses in a general linear model repeated measures analysis of variance (ANOVA) with age group as a between-subjects factor and with two variations of within-subject factors. The more detailed design was a four-way ANOVA: 2 (Head function in main clause: subject, object) × 2 (Case of relative pronoun: nominative, accusative) × 2 (Head position in main clause: initial, non-initial × 2 (RC position: interrupting, non-interrupting). In the second design, we collapsed the first two factors into a Type (4) factor, (SS, SO, OO, OS) and the latter two into a Word order (4) factor, yielding a two-way design: 4 (Type: SS, SO, OS, OO) × 4 (Word order: N-RC-VN, NN-RC-V, NVN-RC, NNV-RC).

There was no significant difference according to age group, $F(1, 41) = 1.76$, $MSE = 13.45$, showing that the average comprehension performance of six- and nine-year-old children did not differ in the experimental task. However, there was large individual variation in both age groups (Figure 1).

Lack of an age group effect is not an artifact of selecting the wrong age ranges for the two groups, as indicated by lack of a significant correlation between average comprehension scores and chronological age (Pearson-correlation = .228, p> .05) in the whole sample. The adult control group, however, performed homogenously at ceiling, significantly outperforming both groups of children, according to multiple post-hoc comparisons (p< .001 for the comparisons with both age groups). This result justifies the selection of children as experimental groups for the present task. As ceiling performance does not allow us to test any effects of working memory capacity or to reveal any patterns, no further analysis is presented on adult data.

In the four-within-subject-factor design, differences according to all of the four factors proved to be significant: Head function in main clause $F(1,41) = 11.02$, $MSE = 1.601$, $p < .01$, Case of relative pronoun $F(1,41) = 9.57$, $MSE = 4.61$, $p < .01$, Head position in main clause $F(1,41) = 15.45$, $MSE = 1.206$, $p < .001$) and RC position $F(1,41) = 32.30$, $MSE = 1.91$, $p < .001$. Only two interactions between within-subject factors reached significance: Head position in main clause $\times$ RC position $F(1,41) = 16.11$, $MSE = 1.21$, $p < .001$, and Head position in main clause $\times$ Head function in main clause, $F(1,41) = 11.87$, $MSE = 1.27$, $p = .001$. There were no significant interactions between structural (within-subject) factors and age group.

The analysis with the two-factor design showed a significant difference according to both Word order $F(3,39) = 13.79$, $MSE = 1.21$, $p < .001$ and Type, $F(3,39) = 5.48$, $MSE = 1.41$, $p < .01$, with no significant interaction between them. In the following we describe the way these structural factors influenced sentence comprehension performance, as it was shown by Bonferroni-corrected pairwise comparisons.

Effects of word order—The main effect of head position in the main clause shows that sentences with the RC attached to the sentence-initial NP were easier. The main effect of RC position revealed that sentences with interrupting RCs were significantly more difficult to process than those with a non-interrupting RC. Note that the head of the relatives was always in focus position in the latter type. These two factors together shed light on differences in comprehension caused by word order patterns. The significant interaction between these factors showed that the most difficult word order is characterised by an interrupting RC attached to the second NP in the main clause, that is, in which the subject and object of the main clause are separated from the sentence-final verb by the RC: NN$_{head}$–RC-V (Figure 2).

In the context of the above interaction, however, the main effect of head position in the main clause should be interpreted with care. The main effects of word order factors may derive from the head position in the main clause and the embedding position of the RC both influencing sentence comprehension independently. However, pairwise comparisons showed that it was only the more difficult NN-RC-V word order (13d) that differed from the others dramatically (p < .001), all comparisons between NNV-RC, NVN-RC and N-RC-VN word orders were not significant. This pattern shows head position in the main clause influences performance only if the RC interrupts the main clause, because no difference were seen between sentences with non-interrupting relatives attached to the sentence-initial versus a non-initial head. Examples for all word order combinations are shown in (13a-d) in the order of difficulty (from easier to more difficult types; all sentences are of SS-type).

(13a) Non-interrupting RC attached to non-initial head (NN$_{head}$V-RC)

A tigrist   az a kutya   csikizte meg, aki   kergette a kecskét.

the tiger-ACC IND the dog-NOM tickled   VM REL.NOM chased   the goat-ACC

'The dog who chased the goat tickled the tiger.'

(13b) Non-interrupting RC attached to sentence-initial head (N$_{head}$VN-RC)

Az a kutya   csikizte meg a tigrist,   aki   kergette a kecskét.

IND the dog-NOM tickled VM the tiger-ACC REL.NOM chased   the goat-ACC

'The dog who chased the goat tickled the tiger.'

(13c) Interrupting RC attached to sentence-initial head (N_head-RC-VN)

Az a kutya,   aki   kergette a kecskétt,   meg csikizte a tigrist.

IND the dog-NOM REL.NOM chased   the goat-ACC VM tickled   the tiger-ACC

'The dog who chased the goat tickled the tiger.'

(13d) Interrupting RC attached to non-initial head (NN_head-RC-V)

A tigrist   az a kutya,   aki   kergette a kecskét,   meg csikizte.

the tiger-ACC IND the dog-NOM REL.NOM chased   the goat-ACC VM tickled

'The dog who chased the goat tickled the tiger.'

Effects of grammatical functions—According to head function relations, pairwise comparisons revealed significant differences only between the SO and the other types: $p < .01$ (SO–SS), $p < .05$ (SO–OS), $p < .01$ (SO–OO); the SS, OO and OS types did not differ. Thus, the relative difficulty of sentence types is OS, SS, OO < SO, the SO type being significantly more difficult than the others (Figure 3).

In more detail, pairwise comparisons in the four-factor ANOVA design showed that the function of the head in the main clause and the case of the relative pronoun in the RC influenced performance differently: subject function proved to be more difficult in the main clause (main effect of head function in main clause) and object function marked by accusative case on the relative pronoun was more difficult in the RC (main effect of case of relative pronoun), without an interaction between the two. Thus, sentences with (i) the RC attached to the main clause object and (ii) with relatives containing nominative case relative pronoun were easier to process for both age groups of children.

Interactions between grammatical functions and word order—The significant Head position in main clause × Head function in main clause interaction is explained by a significant preference for relatives attached to the object (following the subject) in main clauses with NNV word order, while there was no difference between the processing of main clauses with NVN word order according to the function of the head. In other words, as the examples in (14a–d) show, the main clause order of the subject and the object only influenced performance when both constituents were stacking at the beginning of the main clause, that is, sentences like (14a) were significantly more difficult to process than those like (14b). If the sentence-initial head was followed by either the main verb (with non-interrupting relatives) or the interrupting RC, there was not any difference according to head function, thus, processing of sentences in (14c) and (14d) was equally challenging. Note that all four examples contain non-interrupting RCs.

(14a) RC attached to the subject in non-initial position (OS_head V-RC)

A tigrist   az a kutya   csikizte meg, aki   kergette a kecskét.

the tiger-ACC IND the dog-NOM tickled   VM REL.NOM chased the goat-ACC

'The dog who chased the goat tickled the tiger.'

(14b) RC attached to the object in non-initial position (SO_head V-RC)

A tigris   azt a kutyát   csikizte meg, aki   kergette a kecskét.

the tiger-NOM IND the dog-ACC tickled   VM REL.NOM chased the goat-ACC

'The tiger tickled the dog who chased the goat.'

(14c) RC attached to the subject in initial position (S_{head}VO-RC)

Az a kutya   csikizte meg a tigrist,   aki   kergette a kecskét.

IND the dog-NOM tickled VM the tiger-ACC REL.NOM chased   the goat-ACC

'The dog who chased the goat tickled the tiger.'

(14d) RC attached to the object in initial position (O_{head}VS-RC)

Azt a kutyát   csikizte meg a tigris,   aki   kergette a kecskét.

IND the dog-ACC tickled VM the tiger-NOM REL.NOM chased   the goat-ACC

'The tiger tickled the dog who chased the goat.'

The pattern on Figure 4 clearly shows that the main effect of Head function in the main clause is the result of this interaction.

These effects were present in the performance of both age groups. In what follows, we will examine the error patterns to explore the nature of difficulties with the structures that proved to be difficult to process.

Error analysis

In identification of the head of RCs both age groups made significantly more role mismatch than lexical mismatch errors, i.e., they typically chose an appropriate animal (dog or goat) but not the one playing the appropriate role (agent or patient). Errors were categorized according to error type (lexical, role and double mismatches) and main clause head function (subject or object) (we discuss subject-object inversion errors separately later). We conducted a 3 (Error type: role, lexical, double) $\times$ 2 (Head function in main clause: subject, object) repeated measures ANOVA on the average number of errors. A significant difference was seen according to Error type, $F(2,40) = 24.76$, $MSE = 7.207$, $p < .001$, but not according to Head function in main clause, $F(1,41) = 3.13$, $MSE = 2.35$, nor were there significant interactions with age group (Figure 6). Bonferroni-corrected pairwise comparisons showed that role mismatch errors were significantly more frequent than double mismatch errors ($p < .001$), which were in turn significantly more frequent than purely lexical errors ($p < .001$) (Figure 5). The lack of interaction with the head function in the main clause shows that the frequency of all error types was roughly the same for subjects and objects.

This means that in the identification of participants, children did not have difficulties with the interpretation of words but with the processing of the structure of the RC. As a result of misinterpreting the accusative relative pronoun as the subject of the RC, children typically acted out SO type sentences as SS types, and OO type sentences as OS types, i.e. they tended to attribute an agent role to the head within relatives (15a–b).

(15a) SO

Az a kutya, akit   kergetett a kecske,   meg harapta az elefántot.

IND the dog REL.ACC chased   the goat-NOM VM bit   the elephant-ACC

'The dog whom the goat chased bit the elephant.'

(15b) OO

Azt a kutyát,   akit   kergetett a kecske,   meg rúgta a tigris.

IND the dog-ACC REL.ACC chased   the goat-NOM VM kicked the tiger-NOM

'The tiger kicked the dog whom the goat chased.'

Expected interpretation: the tiger kicked the chased dog

Role mismatch error: the tiger kicked the chasing dog

Subject-object inversion, that is, interpreting the main clause object as agent and the subject as patient was more frequent in sentences with a sentence-initial object. This was revealed by a repeated measures ANOVA with Main clause word order as the within subject-factor (2: subject-first, object-first) on the mean number of subject-object inversion errors in subject-first versus object-first sentences. The main effect of Main clause word order was significant, $F(1,41) = 36.14$, $MSE = 5.91$, $p < .001$, while the interaction with age group was not, $F(1,41) = .025$, $MSE = .14$. Bonferroni-corrected pairwise comparisons showed that inversion errors were significantly more frequent when the object preceded the subject in the main clause.

The difficulty with relatives attached to non-initial subjects in main clauses with NNV word order (13c–d) marked by the interaction between Head function in main clause (2) and Head position in the main clause (2) in the original four-way ANOVA was seen mainly because of an outstanding number of subject-object inversion errors. That is, children often chose the sentence-initial object for agent role when the main clause object preceded the subject and the RC was attached to the latter. This was seen in a 2 (Head position in main clause: initial, non-initial) × 4 (Type: SS, SO, OO, OS) repeated measures ANOVA conducted on average number of subject-object inversion errors. Both main effects proved to be significant, Type: $F(1, 41) = 9.39$, $MSE = .62$, $p < .001$, and Head position in main clause: $F(1, 41) = 29.13$, $MSE = .27$, $p < .001$. However, the distribution of S-O inversion errors does not fully mirror the distribution of correct responses. Proportion of correct responses for SS, OO and OS types did not differ from each other, whereas S-O inversion errors for SS and SO types outnumbered those for OO and OS types (as shown by pairwise comparisons). The interaction of Type × Head position in main clause was also significant, $F(3,39) = 11.57$, $MSE = .32$, $p < .001$, revealing that children made more S-O inversion errors in sentences with relatives attached to the non-initial subject in main clauses with NNV word order (Figure 6).

To summarize results of the error analysis, most typical errors involved a role mismatch, suggesting that children had difficulties with processing the morphosyntactic features related to thematic functions rather than with recognizing the lexical items referring to the participants. Inverting the subject and object, that is, interpreting subject as patient and object as agent was typical in sentences where the subject was immediately preceded by the object. This was true even though children did not make more errors in the identification of the object overall. Thus, identification was not burdened by the role of a certain constituent only, but also by the unpreferred sequential ordering of thematic functions, that is, identification of the agent and patient caused problems mainly when the object immediately preceded the subject in the main clause.

Effects of working memory capacity

Individual differences in working memory capacity might be relevant for evaluating some of the comprehension theories attributing difficulties with certain syntactic structures to extra working memory load (Slobin & Bever, 1982; Pléh, 1998; Gibson, 1998, 2000). It is clear from the structural analysis that it is difficult to process interrupted main clauses with two NPs that have to be held in memory until the sentence-final verb is processed. As argued above, if this is really the consequence of a greater working memory load, we expect to find correspondences between structural factors and measures of working memory capacity. In contrast, no such effect is expected on structures that are claimed to be less costly in terms of processing.

We conducted two kinds of analyses to test these effects. First, we included digit span in a regression analysis (nonword repetition and digit span backward was not included as they did not show significant correlation with performance). Digit span explained 23.6% of variance in the data (Table 4).

Second, to explore correspondences between comprehension of certain complex sentence structures and working memory capacities in more detail, we included digit span, nonword span and backward digit span scores as covariates in the original repeated measures ANOVA designs yielding three new analyses. This way, the analysis of variance now took into account the individual differences in the given information-processing abilities as well. Since there was no relevant difference between the three-way and four-way designs, for the sake of simplicity we only report results of the four-way analyses, focusing only on differences between the original analysis and the new ones with covariates.

Controlling for the ability to store and reconstruct sequences of lexical items, that is, using digit span scores representing capacity of the phonological loop as a covariate variable, the effect of age group was still not significant, $F(1,31) = .63$, $MSE = 10.73$. Concerning within-subject factors, only the main effects of Head position in main clause, $F(1,31) = 9.22$, $MSE = 1.19$, $p < .01$, and Case of relative pronoun, $F(1,31) = 6.722$, $MSE = 5.03$, $p < .05$ remained significant. Controlling for the capacity of the phonological loop and the ability to discriminate and reproduce sequences of phonological units, that is, using nonword repetition span scores as a covariate variable, the effect of age group is still not significant, $F(1, 31) = .79$, $MSE = 13.09$, and only the main effect of Head position in main clause, $F(1,31) = 7.09$, $MSE = 1.26$, $p < .05$ remained significant.

Controlling for the capacity of the phonological loop and the function of the central executive, that is, using backward digit span scores as a covariate, the effect of age group is still not significant, $F(1,31) = .224$, $MSE = 13.53$, and none of the within-subject factors reached significance. Comparisons of significance of experimental factors in the original and the three covariate analyses are given in Table 5.

We propose the following interpretation of the results of covariate analyses. Significant main effects and interactions in the original repeated measures ANOVA revealed difficulties in the comprehension of specific structures with certain properties, e. g. embedding position of the RC had a significant main effect showing difficulty of structures containing an interruption. However, problematic structures were not difficult for every child: there were many children who made virtually no errors at all, that is, performance showed great individual variation (see Figure 1). Thus, the difficulty of a certain structure is only manifested in the performance of children with a lower capacity, so differences according to within-subject variables are indeed mapped onto differences between subjects. If the statistical analysis of a bulk of data like this takes into account the individual levels of general processing capacity, then it turns out that errors of sentence comprehension are more frequent in children with weaker working memory capacities, so the significance of structural factors will decrease. Thus, differences between covariate and non-covariate analyses are in part originated in the heterogeneity of children's performance. The order of difficulty of sentence structures is valid in the face of covariate analyses as well, though this is order is only manifest in the performance of children with lower capacity scores in this task. Now we will directly compare analyses with and without covariates, adopting the following logic. A significant main effect eliminated by a covariate variable represents a structural factor that causes problems in comprehension because it charges the specific capacity included as a covariate.

Controlling for the ability to store and reconstruct sequences of lexical items, that is, using digit span scores representing verbal short term storage capacity as a covariate variable, we see that word order factors, such as the embedding position of the RC and its interaction with the head position in the main clause are no longer influential, which indicates that word order factors, or at least the interruption of the main clause produce their effect through charging the ability to store sentential arguments during processing. In other words, interruption of the main clause is difficult for children with relatively weaker verbal short term memory capacity. Interestingly, differences according to the head position in the main clause seem to be less related to short term storage, since this main effect remained significant in this covariate analysis, contrary to the fact that the interaction between head position and head function suggested to underlie the main effect of head position is now eliminated by the covariate. Short term memory does not influence differences according to case of the relative pronoun either, as this main effect remained significant as well.

Controlling for the capacity of verbal short term storage and the ability to discriminate and reproduce sequences of phonological units, that is, using nonword repetition span as a covariate, effects of differences according to head functions as well as word order are largely explainable by the greater burdening of abilities affected in nonword repetition. The short term storage component of this task is similar to the digit span, so our interpretation concerning word order factors is analogous: processing problems caused by words to be stored during listening to interrupted main clauses are linked to weaker short term memory. Difficulties caused by head functions might be accounted for by the phonological discrimination component of the nonword repetition task. The thematic role of the head could only be identified through the recognition of the accusative marker (or the lack of it). However, the accusative suffix is sometimes difficult to perceive. The form of the suffix is a *t* obstruent for stems ending with a vowel, so the accusative form of the relative pronoun *aki* is *akit*, which can be hard to distinguish in some phonetic contexts, e.g. in consonant clusters. Note that in all of the experimental sentences the accusative marking on the relative pronouns appeared in voiceless consonant cluster, since the pronoun was always followed by the verb *kerget* 'chase', e. g. *akit kergetett a kutya* (REL-ACC chased the dog-NOM) 'whom the dog chased'. We argue that children with weaker phonological discrimination abilities might have had difficulties with the recognition of the accusative marker which resulted in the misidentification of thematic roles.

Controlling for the capacity of verbal short term storage and the function of the central executive, that is, using backward digit span scores as a covariate variable eliminates all structural effects. This effect indicates that the structural properties causing difficulties according to the original analysis, e. g. interruption of main clause, or accusative case-marked relative pronouns are problematic because the processing of these kinds of sentences requires a certain level of functioning of the phonological loop and the central executive that some children do not yet master fully. Comprehension of a complex sentence and reversed repetition of a digit sequence involves similar processes: one has to remember the units, assign a sequential structure to them, and perform a kind of coordination (invert the series of digits and inhibit the original sequence in the case of backward digit span, map thematic roles onto syntactic units and inhibit canonic or frequent schemata in sentence comprehension).

Discussion

Results on the comprehension of Hungarian sentences with RCs can be summarized as follows. Comprehension performance did not significantly change between 6 and 9 years, but both age groups showed a great individual variation in comprehension performance. The explanation for this might be that there is no dramatic development in syntactic processing

between the age ranges involved in our sample, but lower working memory capacity in either age group can cause difficulties with certain structures. Instead of maturation of syntactic abilities with age, it seems to be individual differences in working memory that affect processing of complex sentences in these age groups, since both age groups showed the same patterns of difficulties. We now return to the discussion of these difficulties, which reveal what structural factors are at play in the comprehension of RCs.

Word order

Sentences with the most difficult word order combination contained an interrupting RC attached to a non-initial NP, that is, sentences with the NN-RC-V word order (11b) were the most difficult. The interruption of the main clause had a greater effect than the order of NPs in the main clause, since the position of the head in the main clause only made a difference when the main clause was interrupted by the RC. This pattern supports comprehension theories based on working memory processes (Slobin and Bever, 1982; Pléh, 1998 and most relevantly Gibson, 1998, 2000). Note that explicit predictions of the dependency locality theory were fully satisfied, as it was only the combination of the interruption of the main clause and NNV word order that posed extraordinary difficulty for processing compared to any other word order patterns. This might have been attested because–according to the DLT–the double integration of the sentence-final verb with both its arguments at the beginning of the sentence lays an extra burden on working memory resources. The fact that this difference between word orders is eliminated by controlling for short term storage ability measured by digit span levels also supports the approach that the difficulties caused by this word order pattern are due to limitations of storing resources.

This pattern of data makes evaluating MacWhinney (2000)'s perspective-shift hypothesis difficult, since the effect of perspective shift would also be indicated by comprehension differences according to the position of the head in the main clause, but the above described distribution of word order preferences was more precisely predicted and might be more plausibly explained by the DLT without making any reference to perspective change. However, relationships between structural factors and working memory capacities showed that this specific factor, the head position in the main clause is largely independent of working memory capacity, since it remained significant in the ANOVAs controlling for individual short term storage abilities. This result suggests additional difficulties with main clauses with NNV compared to those with NVN word orders. Beside the perspective-shift hypothesis, interference theories also predicted difficulties with NNV sentences due to encoding interference between the semantically similar first two NPs (Lewis and Vasishth, 2005; Lewis et al, 2006). As both perspective and interference theories predict extraordinary difficulties with NNV word orders are similarly borne out, the distinction between them should find further support from analysing the interaction with grammatical functions and error patterns which we will discuss later.

Grammatical functions

According to the grammatical function of the head, a preference for relatives attached to the main clause object was seen as compared to those attached to the subject, in concert with previous results on Hungarian (MacWhinney and Pléh, 1988). However, as it was argued above, this pattern was due to a more specific difficulty with main clauses where the object immediately preceded the subject in a NNV sequence, that is, to an interaction between word order and grammatical functions.

In contrast, the children showed a clear subject-preference in the interpretation of the relative pronoun, i.e. relatives with pronouns in the nominative were easier to process. Error patterns further supported this preference, as the typical error with accusative relative

pronouns was the interpretation of the head as the agent within the RC, contrary to the overt morphological case marker. This preference was predicted on the base of frequency differences in the corpus, a correspondence which was claimed to influence comprehension by experience-based approaches ((Bever, 1970; Mitchell, Cuetos, Corley & Brysbaert, 1995; Tabor, Juliano, & Tanenhaus, 1997; Reali and Christiansen, 2007). The fact that this effect was weaker but still present when short term memory capacity measured by digit span was controlled for suggests that although frequency distributions cause a certain amount of bias in the interpretation of relative pronouns, there are different factors at work beyond working memory capacity. As the effect disappeared when both short term storage and phonological discrimination and reproduction was controlled for, it is plausible to suggest that frequency of occurrence made its impact on comprehension in an interaction with phonological discrimination ability: we propose that children with poorer phonological discrimination abilities tended to disregard the perceptually not very salient–*t* accusative marker on relative pronouns, giving way to the more frequent (agent) interpretation of the relative pronoun.

Correspondences between word order and grammatical functions

In some sentence types, preferences for positions of NPs with certain thematic roles were observed. Main clauses with NNV word order, in which the main clause subject (agent) preceded the object (patient) were easier to process than those with the reversed pattern, and sentence-initial objects typically evoked the inversion of agent and patient in comprehension. These results, in partial agreement with previous data on Hungarian language acquisition (MacWhinney, Pléh & Bates, 1985; Pléh, 1981; MacWhinney and Pléh, 1988) indicate that in difficult contexts children tend to interpret the first referent of the sentence as agent, even in the presence of the accusative case marker. Difficulties with interrupted main clauses with NNV word order were predicted most accurately by the dependency locality theory of Gibson (1998, 2000) and were explained by extraordinary costs of syntactic integration. Nevertheless, the general difficulty with NNV main clauses was still present when storage capacity limitations were controlled for, which suggests that they might not be fully accounted for by storage or integration costs. This suggests some additional difficulties with NNV main clauses, as predicted by both interference theory (Lewis and Vasishth, 2005; Lewis et al 2006) and perspective-shift theory (MacWhinney, 2000). It is difficult to find ways for evaluating these two theories against each other. As neither of them predicted distinct error types, neither can account for the observation that the difficulty with NNV clauses was mainly due to the outstanding number of subject-object inversion errors, and that those errors were more frequent in NNV main clauses when the object preceded the subject. The prediction of the perspective-shift hypothesis is unclear in this respect, since changing the perspective from the object to the subject or vica versa would not necessarily cause subject-object inversion errors. Interference theory would only predict unstable assignment of thematic roles to the semantically similar NPs but would not predict differences according to different ordering of subject and object. Instead of trying to find an account for the complete set of results in terms of either one theory, it is plausible to assume that the difficulty caused either by perspective shift or by the encoding interference between the semantically similar NPs is better explained in terms of the application of the 'agent first' strategy mentioned above. Interpreting the first NP as agent might be a heuristic that resolves the uncertainty in thematic role assignment caused by the difficulties of either perspective shift or the encoding interference. This combination of effects might account for the results, however, without making any distinctions between interference and perspective hypotheses possible. This 'agent first' preference might also have contributed to the tendency for the agent interpretation of accusative relative pronouns, since relative pronouns always occupy the clause-initial position. This tendency might be further strengthened by the factors of frequency of occurrence and perceptibility. As mentioned above, the accusative suffix on the relative pronoun is sometimes difficult to perceive, and the phonetic

context in the experimental sentences might have contributed to missing the case marker in the main clause as well: e. g. the accusative case marker is hard to perceive in *tigrist* 'tiger-ACC' compared to *tigris* 'tiger-NOM', but not in *malacot* 'pig-ACC', compared to *malac* 'pig-NOM'.

Similar patterns, namely, the relative difficulty of processing object relatives (those with an object gap) compared to subject relatives (those with a subject gap) were observed by several studies across languages (Holmes & O'Regan, 1981; King & Just, 1991; Reali and Christiansen, 2007 for English; Schriefers, Friederici & Kuehn, 1995; Diessel and Tomasello, 2005 for German; Carminati et al, 2006; Adani et al, 2010 for Italian; Friedmann and Novogrodsky, 2004 for Hebrew; Friedmann and Costa, 2010 for Hebrew and Portugese; Stavrakaki, 2001 for Greek). It is noteworthy that the stability of this finding across languages is seen despite the fact that languages differ in the way they mark head functions in RCs. For example, the same error types, such as interpreting accusative, genitive and other cases of the head as nominative involves a change in word order in English, while in German and Hungarian it involves modifying or misinterpreting the case marking of the relative pronoun. It is highly possible that the frequency distribution of different case marked forms of the relative pronoun or different types of gaps plays a role in most of the languages as it was shown in the present study for Hungarian as well. Our results are largely concordant with previous findings in Hungarian (MacWhinney and Pléh, 1988), the only significant difference being in the difficulty of OO type of RCs, which were the easiest structure for adult readers in MacWhinney and Pléh (1988), was not confirmed by the present study. This difference might be accounted for by the difference of the studied cohorts and the linguistic material of the studies. First, the participants in MacWhinney and Pléh (1988) were adults, who presumably had a less marked tendency to neglect the accusative case marker of the relative pronoun and thus to interpret the head as agent of the RC. Second, the linguistic stimuli used in the present study might have strengthened the tendency of children to neglect the accusative marker by the difficult phonetic context mentioned above, that constantly made the accusative suffix hard to perceive here, but not in the linguistic material of MacWhinney and Pléh (1988).

It is also worth pointing out that in the present study the preference for the agent-patient order of referents in spite of the presence of morphological markers was observable in school-age children as well. The plausible explanation for this might be the relative difficulty of the task, since the experimental sentences were quite long (18–20 syllables), and consisted of two full-fledged transitive clauses. Children probably would not have neglected case marking and showed a word order preference to the same degree in a less demanding situation, but charging processing mechanisms revealed that this strategy is present at this age as well. As no data is available on the relative frequency distributions of main clause word order patterns in Hungarian, there is no way to tell whether the observed preferences reflect frequency of occurrence in everyday speech, and also, to what degree might word order be considered a reliable cue for the indentification of thematic roles. As have been shown, language type is not the only factor that influences the development of implicit processing strategies: these are shaped by distributions of frequency experienced in everyday language use (Tomasello, 2003). This way, although word order seems to be a much less reliable cue than case marking, processing might rely on most frequent word order patterns in contexts where case marking is less accessible. Differences between the frequencies of occurrence of word order patterns might emphasize the significance of components of working memory in identification of thematic roles. On the one hand, storage functions are of greater importance for the processing of interrupted structures, since incomplete phrases have to be retained actively until the end of the structural unit. On the other hand, the main role of executive functions might be in the inhibition of preferred

sentence interpretations based on frequency patterns in language use, and in the ability to flexible switch between alternative interpretations.

The main motivation for studying the comprehension of RCs in Hungarian was to investigate processing theories independently of each other in a language typologically different from English. The effects of interruption of clauses, the distance between the verb and its arguments, the sentential position of thematic functions and the frequency distribution of RC types were independently proved to be significant, that is, we found independent support for the relevance of each of these factors. It was also shown that the structural factors influencing sentence processing correspond to factors charging working memory capacity more. In other words, differences between the difficulty of comprehension of sentence structures in Hungarian can be formulated in terms of general information processing mechanisms, more specifically in this case, making reference to working memory processes (Gibson, 1998, 2000) and usage-based experience (e.g. Reali and Christiansen, 2007).

The present study invokes several directions for future research. A corpus-based frequency analysis of main clause word order patterns would be of great importance as it potentially sheds light on the tendency referred to as the 'agent first' strategy. The presence of this strategy and other structural preferences should also be studied in language production (see Hsu et al, 2009; Gennari and MacDonald, 2009), a domain that might mirror frequency distributions even more than comprehension. The effect of encoding interference could be tested by studying the comprehension of further variations of word order patterns, e.g. those within the RC that were kept invariant in the present study. The correspondence between syntactic structures and processing resources might be investigated more directly in several ways, one of which is studying RC processing in children with specific language impairment, a population claimed to show sTróng limitations in verbal working memory (e.g. Gathercole and Baddeley, 1990; Marton and Schwartz, 2003; Marton et al 2006, 2007).

Acknowledgments

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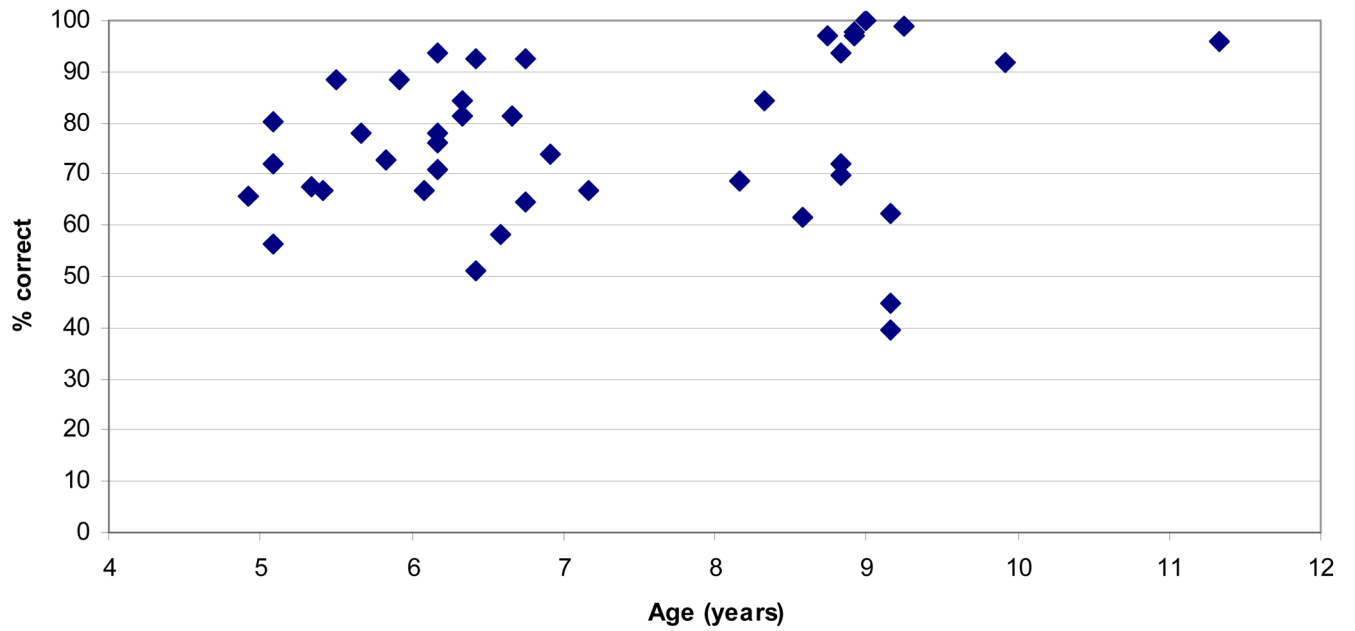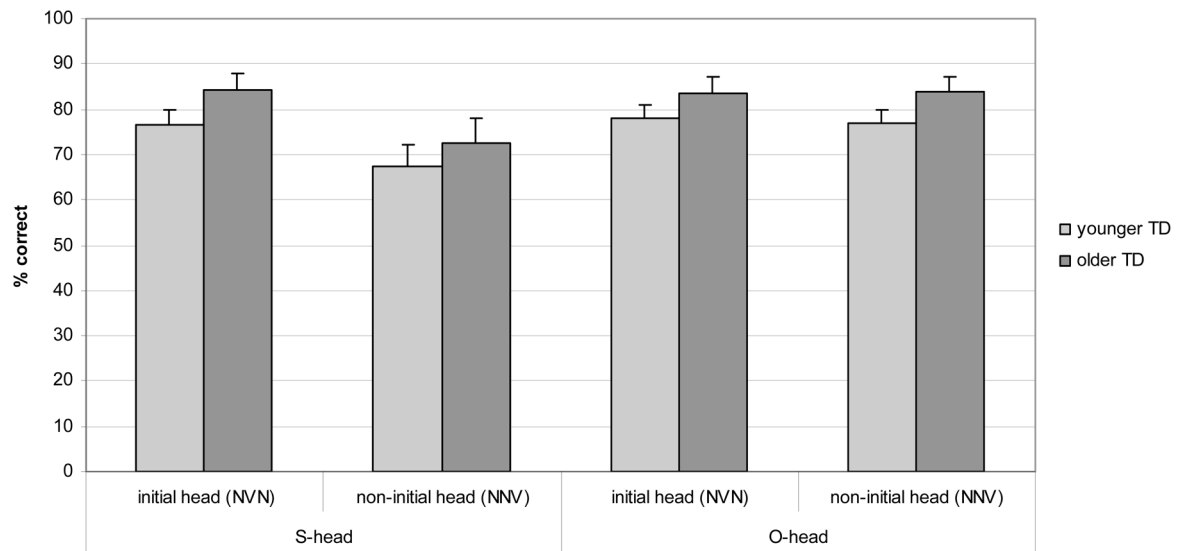
Figure 1.
Individual performance levels in percent correct as a function of age
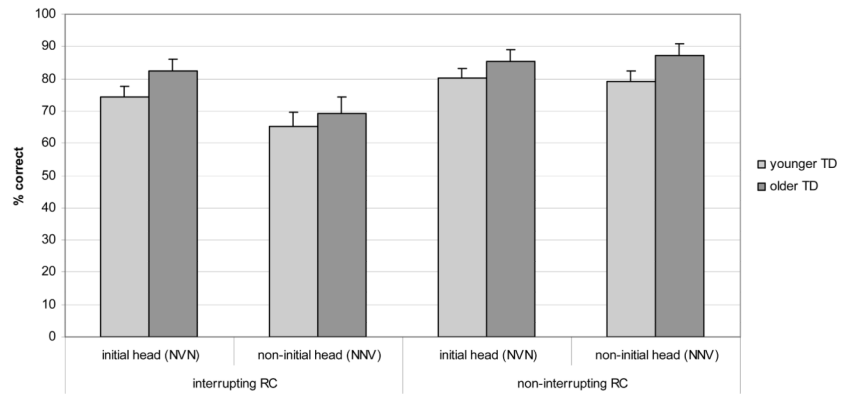
Figure 2.
Percentage correct on sentence types by head position of the in main clause (initial or not) and by embedding position of the relative clause (interrupting or non-interrupting) by age group
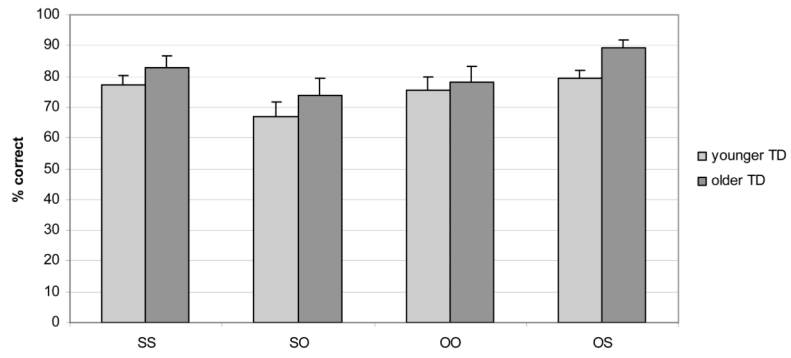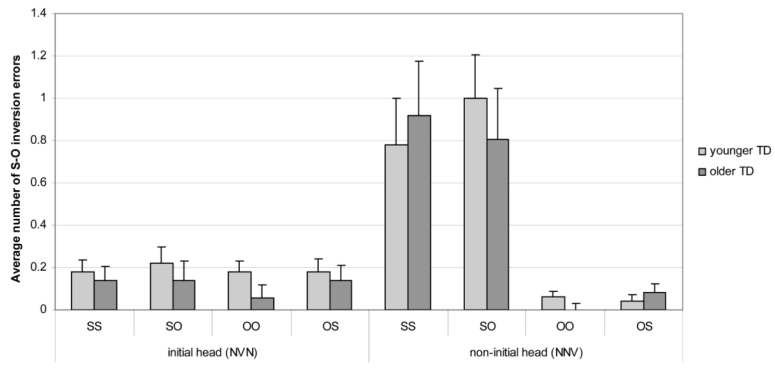
Figure 3.
Percentage correct on SS-, SO-, OO- and OS-relatives by age group

Figure 4.
Percentage correct on sentence types combining head function (subject or object) in main clause and its position (initial or not) by age group
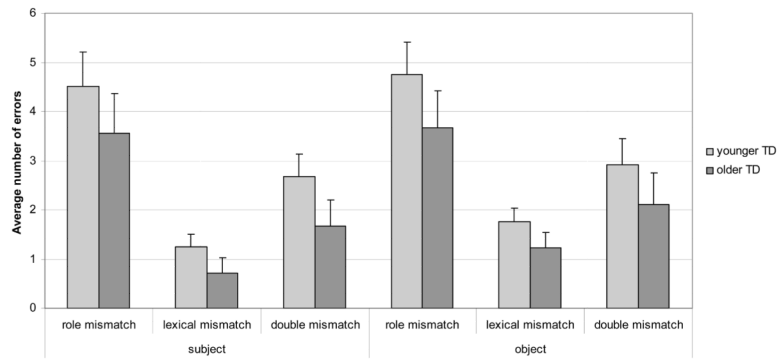
Figure 5.
Average number of different error types in identification of RC-heads as main clause subject or main clause object by age group

Figure 6.
Average number of S-O inversion errors according to sentence type and head position in
main clause by age group

Table 1

Frequency of occurrence of relative pronouns

	aki*	ami*	amely*
all cases	1464442	1352068	1617001
NOM	1137838	618726	918745
ACC	104671	486452	242201

Table 2

Examples for all of the factors and sentence types used in the act-out task (in the glosses all different verb modifiers express perfective aspect and are marked as VM)

head role in main clause	head role in relative clause	head position	RC position	Example
S	S	initial NP	interrupting	Az a kutya, aki kergette a kecskét, meg rúgta a malacot. IND the dog-NOM REL.NOM chased the goat-ACC VM kicked the pig-ACC 'The dog who chased the goat kicked the pig.'
S	O	initial NP	interrupting	Az a kutya, akit kergetett a kecske, meg harapta a majmot. IND the dog-NOM REL.ACC chased the goat-NOM VM bit the monkey-ACC 'The dog whom the goat chased bit the monkey.'
S	S	initial NP	non-interrupting	Az a kutya csikizte meg a lovat, aki kergette a kecskét. IND the dog-NOM tickled VM the horse-ACC REL.NOM chased the goat-ACC 'The dog who chased the goat tickled the horse.'
S	O	initial NP	non-interrupting	Az a kutya simogatta meg a bárányt, akit kergetett a kecske. IND the dog-NOM stroked VM the sheep-ACC REL.ACC chased the goat-NOM 'The dog whom the goat chased stroked the sheep.'
S	S	non-initial NP	interrupting	A macskát az a kutya, aki kergette a kecskét, meg puszilta. the cat-ACC IND the dog-NOM REL.NOM chased the goat-ACC VM kissed 'The dog who chased the goat kissed the cat.'
S	O	non-initial NP	interrupting	A tigrist az a kutya, akit kergetett a kecske, meg lökte. the tiger-ACC IND the dog-NOM REL.ACC chased the goat-NOM VM pushed 'The dog whom the goat chased pushed the tiger.'
S	S	non-initial NP	non-interrupting	A nyulat az a kutya rúgta meg, aki kergette a kecskét. the rabbit-ACC IND the dog-NOM kicked VM REL.NOM chased the goat-ACC 'The dog who chased the goat kicked the rabbit.'
S	O	non-initial NP	non-interrupting	Az elefántot az a kutya harapta meg, akit kergetett a kecske. the elephant-ACC IND the dog-NOM bit VM REL.ACC chased the goat-NOM 'The dog whom the goat chased bit the elephant.'
O	S	initial NP	interrupting	Azt a kutyát, aki kergette a kecskét, meg simogatta a malac. IND the dog-ACC REL.NOM chased the goat-ACC VM stroked the pig-NOM 'The pig stroked the dog who chased the goat.'
O	O	initial NP	interrupting	Azt a kutyát, akit kergetett a kecske, meg csikizte a teknős. IND the dog-ACC REL.ACC chased the goat-NOM VM tickled the turtle-NOM 'The turtle tickled the dog whom the goat chased.'
O	S	initial NP	non-interrupting	Azt a kutyát lökte meg a bárány, aki kergette a kecskét. IND the dog-ACC pushed VM the sheep-NOM REL.NOM chased the goat-ACC 'The sheep pushed the dog who chased the goat.'
O	O	initial NP	non-interrupting	Azt a kutyát puszilta meg a macska, akit kergetett a kecske. IND the dog-ACC kissed VM the cat-NOM REL.ACC chased the goat-NOM 'The cat kissed the dog whom the goat chased.'
O	S	non-initial NP	interrupting	A ló azt a kutyát, aki kergette a kecskét, meg harapta. the horse-NOM IND the dog-ACC REL.NOM chased the goat-ACC VM bit 'The horse bit the dog who chased the goat.'
O	O	non-initial NP	interrupting	A nyúl azt a kutyát, akit kergetett a kecske, meg rúgta. the rabbit-NOM IND the dog-ACC REL.ACC chased the goat-NOM VM kicked 'The rabbit kicked the dog whom the goat chased.'
O	S	non-initial NP	non-interrupting	A majom azt a kutyát simogatta meg, aki kergette a kecskét. the monkey-NOM IND the dog-ACC stroked VM REL.NOM chased the goat-ACC 'The monkey stroked the dog who chased the goat.'
O	O	non-initial NP	non-interrupting	A tigris azt a kutyát csikizte meg, akit kergetett a kecske. the tiger IND the dog-ACC tickled VM REL.ACC chased the goat-NOM 'The tiger tickled the dog whom the goat chased.'

Table 3

Data for children in the younger and older groups and the adult controls

	Age group 1(younger)	Age group 2(older)	Adult control group
Number of persons	25	18	17
Mean age (SD)	6;0 (0;6)	9;0 (0;4)	20;4 (0;8)

Table 4

Digit span as a regression model of comprehension performance

Model	Predicting variable	Beta	P	R^2
1	Digit span	0.48	p<0.01	0.236

Table 5

Comparisons of significance of experimental factors in the original and the three covariate analyses of variance

Factors and interactions	1. analysis (without covariate)	2. analysis (digit span as covariate)	3. analysis (nonword span as covariate)	4. analysis (backward digit span as covariate)
Age group (2)	n. s.	n. s.	n. s.	n. s.
Head position in main clause (2)	**	**	*	n. s.
Relative clause position (2)	***	n. s.	n. s.	n. s.
Head function in main clause (2)	**	n. s.	n. s.	n. s.
Case of relative pronoun (2)	**	*	n. s.	n. s.
Head position in main clause (2) × Relative clause position (2)	**	n. s.	n. s.	n. s.
Head position in main clause (2) × Head function in main clause (2)	**	n. s.	n. s.	n. s.

*
p<0.05;

**
p<0.01;

***
p<0.001