Visualizing Non-Subordination and Multidominance in Tree Diagrams: Testing Five Syntax Tree Variants

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Abstract. In linguistics, it is quite common to use tree diagrams for immediate constituent analysis of sentences. Traditionally, these trees are binary and two-dimensional. However, phenomena such as coordination and right node raising, have led to the view that a simple hierarchical approach of sentences is inadequate: some linguistic phenomena rather seem to involve non-subordination and multiple dependencies. The central question of the present research is this: what are workable alternative tree-like diagrams that can accommodate to this view? An experiment has been set up to test five different types of tree visualizations, including three-dimensional trees. Subjects were asked to respond to various questions concerning coordination and (non-constituent) right node raising constructions, and to mark their preference for each tree visualization. This paper will discuss the representation problems, and present the experiment and its results. It turned out that the tree most rich in information was the least usable one, whereas the tree, most close to the traditional syntax tree, but with colour enrichment, performed best.

Key words. tree diagrams, non-subordination, multidominance, usability

1 Introduction

In this paper we test representations of information that can mostly be ordered in a hierarchical way, but, for some part, goes beyond hierarchy. Five tree-like diagrams have been designed to represent these data. An empirical test has been set up in order to see which tree visualization would come out as the most usable one.

Tree diagrams, also called hierarchies, are a way to visualize hierarchically ordered information, not only in non-scientific, but also in scientific contexts. As a scientific diagram, the tree diagram belongs to the category of schematic diagrams [11, 15]. Schematic diagrams are abstract diagrams that provide an overview of the components and their organization of a set of raw data according to some model. Not only in science education, but also in scientific research, they are an important tool for thinking and reasoning. They often serve as an external memory device for multilevel hierarchical information, such as class inclusion or componential analysis. Being schematic diagrams, they rely on learned conventions [15, 14]. They are not restricted to one specific application domain. They are so-called domain-general diagrams. As a consequence, most people are familiar with them. They know how to create and use them, and reason with them.

Tree diagrams also occur in the domain of linguistic theory. Harleman Stewart [10] points out that the tree in linguistics bears at least four meanings: genesis, taxonomy, componential analysis, and constituent analysis. The type of data represented and the context of use of the tree determines which meaning should be assigned to it. If the data is a sequence of word tokens constituting a natural language sentence and the context of use is the linguistic subdomain of generative syntax, the meaning of the tree diagram is the immediate constituent analysis of the sentence. The tree depicts the sentence in terms of its constituents. It shows which word token units are constituents of which constructions at which level. An example is the tree in Fig 1.

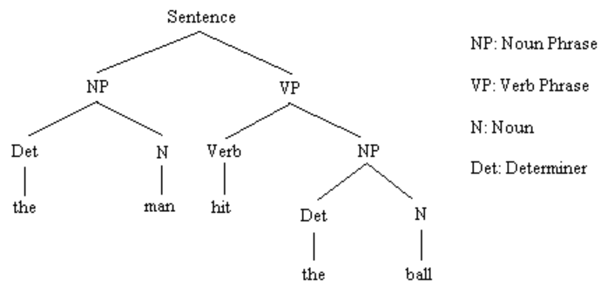

Fig. 1. Constituent analysis of the sentence *The man hit the ball* [6][1]

In the context of generative syntax, tree diagrams are also called syntax trees. It should be pointed out that the process by which diagrams in linguistics are interpreted is a process of circular reasoning. Diagrams are used to make statements about linguistic data for which the questions raised have already been answered. So diagrams in linguistics are merely used to convey and idea, and are not designed for helping to solve a linguistic problem. In terms of information visualization, they visualize the data according to a given, predetermined view. They are not intended to 'amplify cognition', i.e. to solicit visual thinking in order to get new ideas [4].

Graphically, the syntax tree is a set of nodes and branches. As for their arrangement, it follows the definition of an ordered binary two-dimensional tree. The vertical dimension expresses succession, not in time or space, but in the sense of substitution. In the example above, NP, for instance, gives way to Det and N, VP is substitutable by Verb and NP, and so on. In linguistic terms, the branches represent relations of dominance or subordination. The horizontal dimension expresses a relation between sentence parts that are not substitutible one for another. In the example above, Det and N form one constituent, verb and NP another. Node and branch also express constituent function. The difference between Subject (*the man*) and Object (*the ball*), for instance, is conveyed in the example above, by a left branching NP from Sentence versus a right branching NP from Sentence via VP. Whereas most tree diagrams require

[1] Note that Chomsky used the symbol T instead of Det for determiners.

units to appear at the nodes, in immediate constituent trees, no units need to appear at their nodes. The expression of immediate constituent analysis is unhampered by the lack of category symbols like NP, VP, and so on. The terminal units form the basic data of the tree. At the terminal level, the horizontal dimension expresses the order in which the terminal units, i.e. the word tokens, appear in the sentence. In linguistic terms, the horizontal axis expresses the relation of precedence. Both vertical and horizontal relations are asymmetric.

Since Chomsky [6], things have changed a lot: new models have appeared, new ideas have been proposed. For quite a long time, the traditional syntax tree could accommodate fairly well to all these changes, until syntax got interest in so-called paratactic phenomena[2] and new theories were produced about these, starting with McCawley [13] (see also [8, 23, 9, 19, 12]). Generative syntax has indeed been preoccupied by hypotaxis for a long time. Hypotactic relations are relations of subordination. Sentence (1) is an example.

(1) He couldn't come because he was ill.

The sentence part *he was ill* is subordinated to *he couldn't come*. However, natural language sentences are not restricted to hypotactic relations between sentence parts, but also manifest paratactic relations. Coordination and parenthesis, for instance, exemplify parataxis. (2) is an example of coordination, (3) of parenthesis.

(2) The man was sitting and the woman was standing.

(3) I told them, mistakenly, it turned out, that she had already left.

In (2), *the man was sitting* is coordinated to *the woman was standing*. These two sentence parts are called conjuncts of the coordination. In (3), *mistakenly, it turned out* is a comment clause inserted in the main clause. Coordination often gives rise to a special construction, the so-called 'right node raising' construction, as exemplified by (4). 'Right node raising' is also known as 'backward conjunction reduction'.

(4) Mary wrote and John signed the letter.

In (4), where the intonation pattern is such that the verbs *wrote* and *signed* are accentuated, the object NP *the letter*, which is a full constituent, is shared by both conjuncts of the coordination, viz. *Mary wrote NP* and *John signed NP*. Sharing does not always involve whole constituents, as demonstrated by (5).

(5) John offered, and Mary actually gave a gold Cadillac to Billy Schwartz.

In (5), the two conjuncts *John offered NP PP*[3] and *Mary actually gave NP PP* share a sequence of phrases and words, viz. *a gold Cadillac to Billy Schwartz*, that does not form a constituent.

Linguists do not quite agree on the way how to account for paratactic relations and how to deal with conjuncts sharing constituent or non-constituent parts of a sentence. In this paper, it is assumed that sentences with coordination imply a third asymmetric relation, alongside those of dominance and precedence. This relation is called non-subordination. It is further assumed that right node raising constructions involve multidominance. Non-subordination and multidominance are views put forward by de Vries (see [20, 21, 22]) in order to account for the connection between conjuncts of a coordination. When a node N_1 is in a relation of non-subordination with another node

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[2] In grammar, parataxis refers to phrases and clauses arranged independently.

[3] PP stands for prepositional phrase.

N_2, N_2 can be viewed as lying behind N_1. Subordination constitutes the first representation problem for the traditional syntax tree.

The other representation problem is the relation of multidominance, i.e. the sharing of nodes. In an ordered binary tree, one node is replaced by one or more nodes at a lower level. Dominance is indeed a one-many relation. Ordered binary trees do not allow for several nodes being replaced by one node at a lower level.

So, non-subordination and multidominance challenge the representational properties of the traditional syntax tree.The two representation problems raised first led to the question how to modify the traditional and among linguists commonly accepted and well-known tree diagrams in order to convey the new theoretical views on paratactic phenomena in natural language. With the renewed and expanding interest in visualizations of all types, design theories offer interesting visualization techniques for optimizing representations of all kinds of data [2, 18, 4]. We have made use of some of these to enrich the traditional tree diagrams in order to represent visually the new syntactic views. The enrichments led to five alternative solutions. These various options then raised a second question, namely the queston which enrichment would be the most usable one. In order to answer this question, an experiment has been set up to test the usability of the five alternatives designed. Performance of the task, which consisted in answering a series of questions on syntactic configurations, was measured by the registration of error rates and response times. User preference for the various tree diagrams was measured as well.

2 The five visual enrichments of the traditional syntax tree

The preliminary condition for all alternative tree diagrams was to maintain the hypotactic information as visualized by the traditional syntax tree following X-bar theory (for Dutch syntax, see [1]). The five alternatives differed with respect to the visualization of non-subordination and multidominance. Below we show the five tree diagrams proposed. All trees have been composed in Blender, the open source, cross-platform suite of tools for 3D creation.

All five trees visualize the structure of five different, but comparable, Dutch sentences illustrating each coordination with non-constituent right node raising. The structure of these sentences all involve non-subordination and multidominance.

The tree in Fig. 2 is called the 2D variant. It is most close to the traditional two-dimensional tree diagram. It has only a special accommodation for multidominance relations. These are marked by red-colored branches. The tree in Fig. 3 is labelled 2D+. It is like 2D in that it has color coding for multidominance. Moreover, it marks the different syntactic categories at the internal nodes as well by different colors. These also determine the final colors of the multidominance relations. Fig. 4 shows a three-dimensional tree, called 3D. It is like 2D, augmented with a special encoding for non-subordination. The two conjuncts of the coordination are represented as two subtrees, one behind the other at a third dimension, and connected to each other by a pink-colored branch.Figure 5 shows the 3D+ variant, which is like 3D, but adds to it the color marking of 2D+ of the internal nodes. 3D+ is the most rich tree from a graphical and a semantic point of view.

D_planes, illustrated by Fig. 6, overlaps with 2D, but differs from it by representing the conjuncts as subtrees in different planes, thus creating a pseudo three-dimensional picture. Finally, it should be noted that an important concern for the composition of each of the above trees was clutter. Clutter has been avoided as much as possible

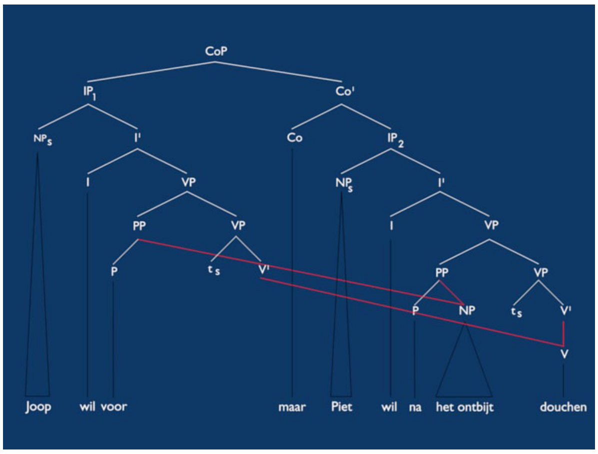

Fig. 2. 2D tree visualizing the structure of Dutch *Jan wil voor maar Piet wil na het ontbijt douchen* (Eng. *John wants before but Peter wants after breakfast to take a shower*)

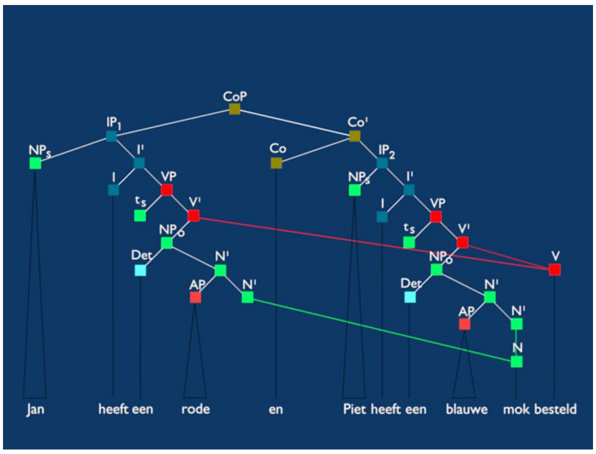

Fig. 3. 2D+ tree visualizing the structure of Dutch *Jan heeft een rode en Piet heeft een blauwe mok besteld* (Eng. *John has a red and Peter has a blue cup ordered*)

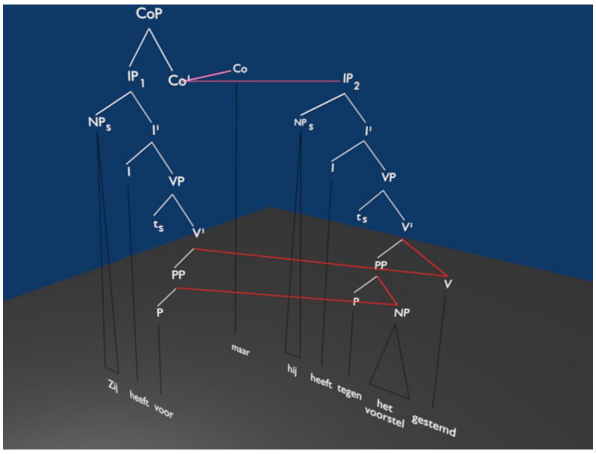

Fig. 4. 3D tree visualizing the structure of Dutch *Zij heeft voor maar hij heeft tegen het voorstel gestemd* (Eng. *She has for but he has against the proposal voted*)

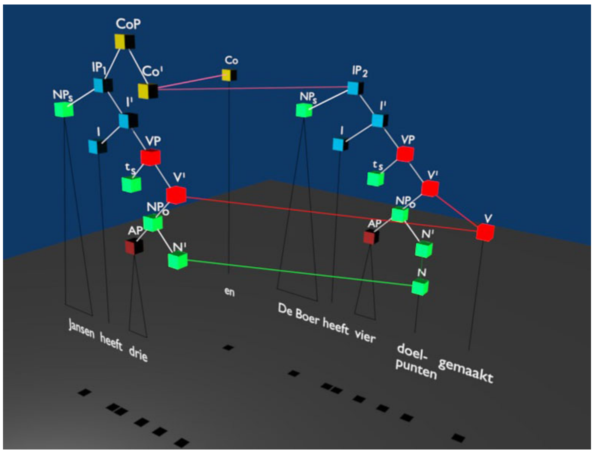

Fig. 5. 3D+ tree visualizing the structure of Dutch *Jansen heeft drie en De Boer heeft vier doelpunten gemaakt* (Eng. *Jansen has three and De Boer has four goals made*)

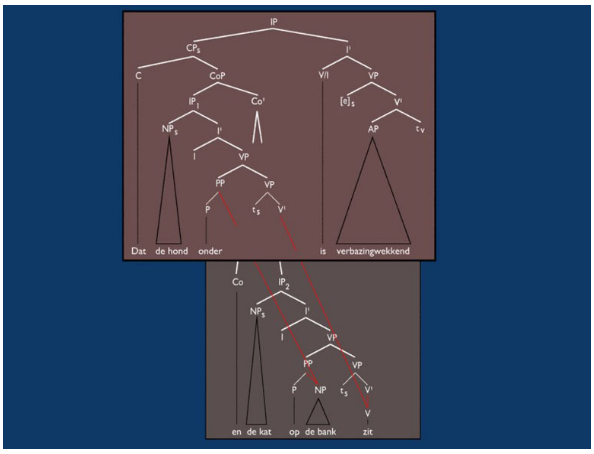

Fig. 6. D_planes tree visualizing the structure of Dutch *Dat de hond onder en de kat op de bank zit is verbazingwekkend* (Eng. *That the dog under and the cat on the bench sits is surprising*)

3 The experiment

An experiment has been set up to test the usability of the above enriched syntax trees. What did we consider to be the likely outcome? From an information visualization point of view, one might be tempted to think that the richer the tree in structure and color, the more informative the representation is, and the more usable it will be for the illustration and demonstration of, and reasoning with non-subordination and multi-dominance. Three-dimensionality would signal coordination and its conjuncts, the color coding of the internal nodes would make it easier to recognize and identify phrases belonging to a certain syntactic category, and the color coding on the branches would help to see the deviant types of links, viz. those indicating non-subordination on the one hand, and those indicating multidominance on the other hand. However, this positive view on semantically rich representations might be tempered by sceptical cognitive views (see [16, 5] among others). Moreover, in the literature on the use of graphical representations in instruction and user interfaces, one can also find observations that run counter to the expectation that informationally rich diagrams will be appreciated by their users. In [3] for instance, it is pointed out that the more familiar the diagram, the easier it is to process. New diagrams have to be learned in order to be effective in the sense of facilitating a task. Results from empirical research show that three-dimensional visualizations in user interfaces are not necessarily easier to process than their two-dimensional variants (see [17, 6]).

Forty-six persons served as subjects in this study. This group contained 24 females and 22 males. All of them had native or near-native knowledge of the Dutch language. Ages varied between 18 and 65. All of them either followed or had finished a

university education. With respect to the background knowledge in the specific application domain of generative syntax, three different groups could be distinguished. One group of 17 subjects (8 males, 9 females) with ages varying from 18 to 65, did not have any education in syntax. For us this was the group with no background knowledge. The second group, a group of 18 students of the faculty of Arts of the University of Groningen (9 males, 9 females, with ages varying from 18 to 30) got some introductory course in generative syntax. They could be seen as the group with weak background knowledge. The third and last group contained 11 experts (5 males and 6 females) in the field of generative syntax. They had finished a linguistic education at the university and some of them have got a Ph.D.. It was the group with strong background knowledge. Evidently, the expert group was most familiar with the traditional syntax trees, and their conventions, the laymen were least familiar with them. For all subjects, the enriched trees were new. The two-dimensional tree diagram as domain-general diagram could be considered common knowledge of all subjects.
The five enriched syntax trees were tested in a web-based application. The application consisted of five parts:

1. The web-based test started with a page where the subjects were asked to enter age, sex, education and background knowledge.
2. A short introduction and help was provided explaining and illustrating the syntactic category symbols as used in X-bar theory, and the notions of constituency, dominance (or subordination), and coordination. The notions and symbols were illustrated with the help of the traditional syntax tree.
3. The actual test showed the five enriched trees visualizing three sentence constructions in Dutch, viz. coordination, constituent right node raising and non-constituent right node raising. Fifteen different pictures were shown to each subject, who had to answer three different type of questions for each picture. Each subject was thus solicited to inspect each of the five tree variants on the basis of nine questions. The actual test covered forty-five pages.
4. After the questions, a page summarized the five enriched syntax tree variants and asked the subject to mark his preference for each tree on a Likert scale with five values, ranging from very good to very bad.
5. The test was closed by thanking the subject. The subject could also give his or her comments on this page.

The independent variables of the experiment were the type of tree diagram (five levels), the degree of syntactic background knowledg (three levels), the syntactic construction type (three levels), and the question type (five levels). The dependent variables were error rate, performance time, and user preference. The experiment was conducted as a within-subjects design.The main interest of the study was in the manipulation of the tree diagram. Transfer of learning effects were lessened by varying the order of the five trees between the subjects, and by varying the content of the trees. The three construction types were illustrated in each visualization type by different sentences, as shown by Fig. 2-6 above. The questions were formulated as yes-no questions and in domain knowledge terms of the notions explained in the introductory and help page. For instance, the questions asked with respect to the 2D tree in Fig. 2 were the following (below, they are given in Eng.):

1. Is *voor het ontbijt douchen* a constituent?
2. Are IP_1 and Co dominated by the same nodes?
3. Is V dominated by PP in the first conjunct?

From the diagrammatic view proposed by Novick and Hurley [15], who distinguish three categories of properties of hierarchies, the questions required the subject to consider the basic structure of the tree, as well as details about the nodes and links in the tree, and potential movement of information through the tree.

The subjects were invited to take the web-based test in their own time at a quiet place.

4 Results

The question which tree is the most usable one for the representation of non-subordination and multidominance relations is answered by looking at the scores on the three different usability aspects measured for each tree. The global results are given in Fig. 7, 8 and 9 below. Fig. 7 gives the results in percentages for the mean number of errors made for each visualization type. A proportion test revealed that the difference between 2D+ and D_planes, on the one hand, and 2D, 3D and 3D+, on the other hand , is significant ($p < 0.05$). In Fig. 8 , the mean response times are given for each visualization type. The subjects took most time for answering the questions with the 3D+ variant. The difference of 3D+ with each of the other visualization types turned out to be significant, as indicated by a MANOVA test (Bonferroni post hoc, $p<0.05$). Fig. 9, at last, shows the preference results. These are the subjective judgments made by the subjects on each visualization type. It is clear that the tree the subjects liked best was the 2D variant. The differences are significant for 2D versus the other visualization types, for 2D+ versus 3D+ and D_planes, and for 3D versus 3D+ and D_planes, as shown by a One-way ANOVA test (Bonferroni Post Hoc, $p<0.05$).

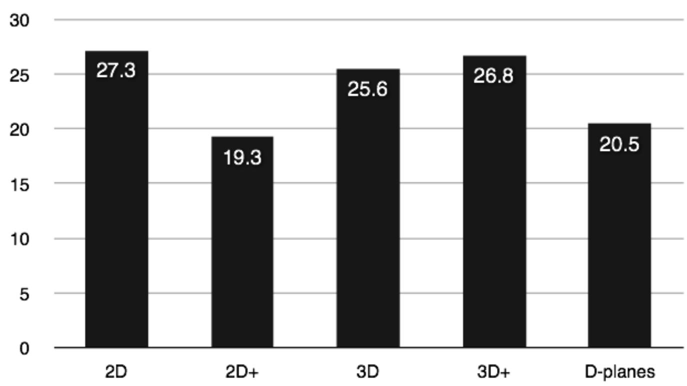

Fig. 7. Mean error rate per visualization type (in %)

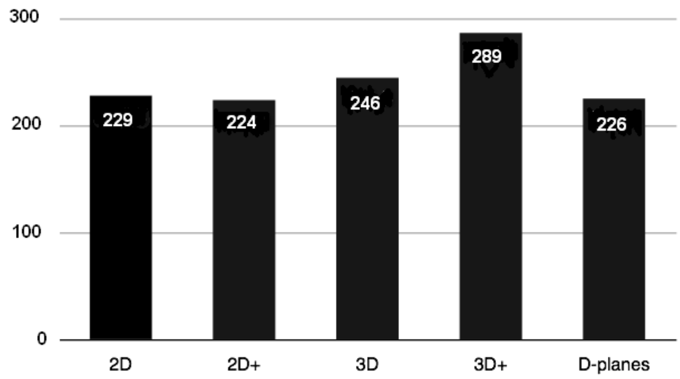

Fig. 8. Mean response times per visualization type (in sec.)

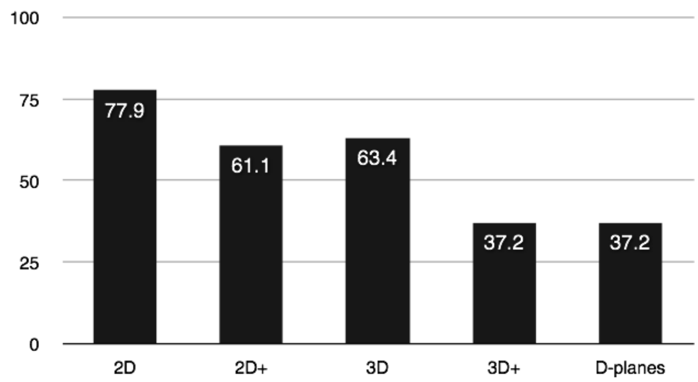

Fig. 9. Subjects' preferences per visualization type (100% = very good; 0%= very bad)

When we look at the overall results of the experiment, we can conclude that none of the enriched syntax trees has the best score on all three usability aspects measured. As for error rate, 2D+ scored best, as for response times, 2D+ scored best as well, but 2D scored best with respect to preference. 3D+ scored second worst on error rate, and worst on response time. Together with D_planes, it is the worst appreciated tree diagram. If all usability aspects are assigned equal weights, one can say that 2D+ is the overall winner, and, surprisingly, that 3D+ is the overall loser.

Worth mentioning are also some more local results, especially those differentiated between the three subject groups. In Table 1 and 2 below, we see that the group with strong domain knowledge performed best in the least time. The group with no domain knowledge performed worst, but, as for error rate, did quite well in comparison with the weak domain knowledge group. Strikingly, all groups were unanimous in their preference for 2D. 3D+ was disliked by both strong and weak domain knowledge groups, while the laymen were more positive about it, and disliked the D_planes version. Notably, the latter scored nearly as well as 2D+. It can further be noted that the two 3D variants (3D and 3D+) are neither popular, nor lead to optimal performance.

Table 1. Total test mean error rate (in %) and mean response time (in min.) per subject group

Domain knowledge	*mean error rate (%)*	*mean response time (min.)*
strong	12	17
weak	26	18
no	30	26

Table 2. Interesting visualization type results per subject group

Domain knowledge	*most preferred*	*least preferred*	*least errors*	*least response time*
strong	2D	3D+	2D+	2D
weak	2D	3D+	D_planes	2D+
no	2D	D_planes	2D+	2D+

When we look at the construction types (see Table 3 and 4 below), it can be observed that for constituent right node raising (const. RNR), most errors were made with the 2D and 3D+ diagrams. This was a pattern demonstrated by all groups. Also, 3D+ took most time for the subjects of all three groups to answer the questions about coordination (coord.) and constituent right node raising. Globally, non-constituent right node raising (non-const. RNR) turned out to be the least problematic construction, although D_planes was here the least facilitative tree diagram.

Table 3. Error rate for each visualization type per construction type

Construction type	*2D*	*2D+*	*3D*	*3D+*	*D+planes*
coord.	30	32	36	27	27
const. RNR	56	30	39	59	25
non-const. RNR	27	18	31	25	33

Table 4. Response time (sec.) for each visualization type per construction type

Construction type	*2D*	*2D+*	*3D*	*3D+*	*D+planes*
coord.	215	227	276	325	215
const. RNR	234	247	243	337	195
non-const. RNR	237	199	218	204	269

5 Conclusion

The main goal of the experiment was to test the usability of five variants of tree diagrams augmented with extra graphical elements to encode non-subordination and multidominance relations, which are assumed to be implied by syntactic constructions such as coordination and right node raising. It turns out to be difficult to answer this question unambiguously. 2D+ does a good job, and 3D+ does not, suggesting that color coding influences understanding of the new relations introduced positively, and that the addition of a third dimension is not facilitative at all. A two-dimensional syntax tree seems to be easier to process than a three-dimensional one. Familiarity seems to influence user preference strongly. 2D trees are familiar, and people like to use them, probably because they know how to interpret them. Apparently, subjects did not prefer the tree diagram which facilitated most the task performance. Which tree diagram can best be used to convey the views on parataxis as illustrated by coordination depends on the values attached to the different usability aspects. If preference is more important than correct and fast understanding, then we can stick to the variant most close to the traditional syntax trees. If not, we can opt for the 2D+ variant. It has also been shown that domain-specific knowledge plays an important role in task performance with the syntax trees, supporting research findings on schematic diagrams in other domains (Novick, 2006). The experiment relied on tree diagrams composed in a particular way in Blender. It might be the case that three-dimensional trees designed in another way will be more facilitative. We think that the results of this experiment show that visualization techniques should be applied with care, and that learning and cognitive aspects should be taken into account in the design of novel diagrams, even when these rely on familiar ones.

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