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Working Memory Constraints on Multiple Center-Embedding

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Abstract

Gibson's (1998) theory on the locality of syntactic dependencies claims that multiply center-embedded clauses are unacceptable if they contain a parse-state with at least two long unresolved predicted categories in addition to the top-level verb. 'Long unresolved' means a syntactic prediction spanning at least three intervening new discourse referents. This claim was based on experimental analysis of invented examples. Karlsson (2007b) provided corpus data demonstrating that, contrary to widely accepted views in linguistics and cognitive science, there are well-defined constraints on how many (maximally three) and what types of multiple center-embeddings occur in spoken and written discourse in natural languages. Gibson's theory of the processing of multiple center-embeddings will be evaluated in the light of Karlsson's empirical data. The corpus data do not support the idea of a discrete limit on working memory capacity, because almost one third of the extant examples of multiple center-embedding are more complex than Gibson's acceptability limit stipulates. Spoken language processing complexity is clearly below Gibson's limit, written language is capable of transgressing it.

Keywords: center-embedding; clausal embedding; cognitive explanation; complexity; embedding; multiple center-embedding; recursion; syntactic complexity.

Definition of Center-Embedding

The notion EMBEDDING refers to all types of clauses occurring as subordinate parts of their superordinate clauses (which themselves may be either main or subordinate). The starting point will be the classical view of subordination as expounded in Quirk et al. (1989, Chapter 14). Typical finite sub-clauses are of three types: complement, relative, and adverbial. They are indicated by subordinators or relative pronouns, henceforth called sub/wh-elements.

CENTER-EMBEDDED clauses have words of the superordinate clause both to their left (excluding subordinators and coordinators) and to their right, as the relative clauses in (1, 2) and the *when*-clause in (3). SELF-EMBEDDING is multiple center-embedding invoking two or more clauses of the same type, e.g. two relative clauses as in (4). In the examples, the gross clausal structure is indicated by angular brackets prefixed by the character 'C' for center-embedding and an integer indicating dept of embedding.

(1) Others [$_{C\text{-}1}$ who are attracted to this Mecca of the beat generation] are heroin addicts and small hoodlums. (Brown Corpus)
(2) Another frequent pioneer difficulty, [$_{C\text{-}1}$ caused by wearing rough and heavy shoes and booths,] was corns (Brown).
(3) On March 13, [$_{C\text{-}1}$ when he preached a sermon on the text,] he told his congregation how disappointed he was (Brown).
(4) For an analysis of the possible modifications [$_{C\text{-}1}$ of which the pathological termination of an act [$_{C\text{-}2}$ which is not according to law] are susceptible] we have therefore ... (Jeremy Bentham)

When a sentence contains multiple embeddings of the same type, e.g. two center-embeddings as in (4), the DEGREE OF EMBEDDING is equal to the number of embeddings and occasionally indicated by the character 'C' superfixed with the degree. Thus, (4) is an instance of C^2, double center-embedding.

A clause embedded after the initial subordinating (or coordinating) conjunction of the superordinate clause is not center-embedded but initially-embedded, e.g. the I-2-clauses in (5, 6):

(5) [$_{I\text{-}1}$ If [$_{I\text{-}2}$ what is tantamount to dictatorship ...] continues in a union] it can ... (Lancaster-Oslo/Bergen Corpus = LOB))
(6) c. [$_{I\text{-}1}$ If [$_{I\text{-}2}$ when I'm 38] Metallica ends] I don't think ...] (British National Corpus = BNC)

Here, the subordinating conjunctions of the respective I-1-clauses are not fully integrated syntactic constituents in their clauses and therefore a further clause embedded after them is not center-embedded but initially-embedded. The superordinate clause material preceding a center-embedding must consist of full syntactic constituents, as in (1-4).

Empirical data on multiple center-embedding

By systematically searching the Brown and LOB corpora, by checking the extant scarce empirically-minded literature on multiple center-embedding, by consulting more than 100 older grammars, style manuals and philological studies especially of older forms of German and Latin, and furthermore by manually analyzing 6000 sentences by three 19th century scholars known for their intricate and syntactically complex language use (Jeremy Bentham, John Stuart Mill, C. S. Peirce), Karlsson (2007) established a data pool of 13 triple center-embeddings, C^3, and 104 double center-embeddings, C^2. As every C^3 contains two C^2s, the total number of C^2s is 130. The languages concerned were English, German, Latin, Swedish, Finnish, French and Danish, from Antiquity to the 21st century.

Here are three of the C^3s observed:

(7) In an excellent article ... Salvini draws a parallel between the way [$_{C\text{-}1}$ in which the spoken Latin of the men [$_{C\text{-}2}$ with whom Gregory of Tours, [$_{C\text{-}3}$ whom he has no reason to mention,] must have mixed] eventually became Old French ...,] and the comparable direct development of pre-Romanesque painting ... (L. Thorpe, *Gregory of Tours: The History of the Franks*, 1974; due to Geoffrey Sampson)

(8) The Prime Minister [$_{C\text{-}1}$ who at the height of the crisis had snapped to a junior minister [$_{C\text{-}2}$ who, [$_{C\text{-}3}$ not having seen him for some time,] had approached him in a Westminster corridor with a view to wishing him luck …,] 'If you want to resign, put it in writing',] was unlikely to ... (Patrick Cosgrave 1979; De Roeck et al., 1982)

(9) A person [$_{C\text{-}1}$ who, [$_{C\text{-}2}$ when riding a cycle, [$_{C\text{-}3}$ not being a motor vehicle,] on a road or other public place,] is unfit to ride through drinks or drugs,] shall be guilty of an offence. (*British Road Traffic Act*, 1972; Hiltunen, 1984)

Here are four C^2s ('F' = finally-embedded clause; '&' coordinated clause):

(10) And yet a widow, [$_{C\text{-}1}$ whose pension, [$_{C\text{-}2}$ for which her husband paid,] is wiped out [$_{F\text{-}2}$ because she works for a living wage,]] will now ... (LOB)

(11) At one point in the game [$_{C\text{-}1}$ when the skinny old man in suspenders [$_{C\text{-}2}$ who was acting as umpire] got in the way of a thrown ball] [$_{\&C\text{-}1}$ and took it painfully in the kidneys,] he lay there ... (Brown)

(12) ... the girl ... [$_{C\text{-}1}$ who was clothed in the tightest-fitting pair of slacks [$_{C\text{-}2}$ I had ever seen on a woman] and a sweater [$_{F\text{-}2}$ that showed everything [$_{F\text{-}3}$ there was]]] wanted to be sociable.] (Brown)

(13) But the idea [$_{C\text{-}1}$ that the fact [$_{C\text{-}2}$ that some pain is heading my way] gives me no special reason to avoid it] seems so at odds with ...] (Internet)

On the basis of the material collected, Karlsson (2007) induced the following generalizations:

(14) The maximal degree of multiple center-embedding is three in written language, but C^3 is so rare as to be practically non-existing (only 13 instances found).

(15) The maximal degree of multiple center-embedding is two in spoken language, but it is so rare as to practically non-existing (only three instances found).

(16) Only clauses that postmodify nouns (i.e. relative clauses as in (7, 8, 10 12), complement *that*-clauses as in (13), and indirect questions allow central self-embedding.

(17) A C^2 must contain at least one postmodifying clause.

(18) The typical C^3/C^2 contains a pair of relative clauses, and is located at the end of the grammatical subject immediately before the main verb. Its main function is to aid in the specification of the topic of the sentence.

(19) A/the lower clause in a multiple center-embedding must contain at least one overt pronoun, preferably as grammatical subject.

(20) Direct objects must not be multiply relativized in C^2s or C^3s.

In practice, constraint (15) rules out multiple center-embedding in spoken language. This means that genuine rested syntactic recursion under no circumstances can be considered an important design feature of natural language syntax.

Constraint (18) is explicable by the fact that the S-V junction is the major natural syntactic break in SVO-languages, between the topic (the grammatical subject) and the comment.

Constraint (20) rules out the classical sentence (21), even if (21) is in conformance with constraint (14). Sentence (21) has often been used in the literature as supposed proof of the absence of constraints on the degree of multiple center-embedding.

(21) The rat$_j$ [$_{C\text{-}1}$ the cat$_k$ [$_{C\text{-}2}$ the dog$_m$ chased _$_k$] killed _$_j$] ate the malt.

Not a single genuine example of double object relativization was found in Karlsson's (2007) corpus, nor are there any in the literature known to me. (In (21), the traces of the preposed objects are indicated.)

Gibson's processing theory

Edward Gibson's (1998) Syntactic Prediction Locality Theory (SPLT) has been influential in accounting for the relationship between the sentence processing mechanism and the available (mental) computational resources.

The theory has two components: an INTEGRATION COST component and a component for the MEMORY COST associated with keeping track of obligatory syntactic requirements. The type of memory concerned is, of course, working memory (WM). WM cost is quantified in terms of the number of syntactic categories that are necessary to complete the current input as a grammatical sentence. Both memory cost and integration cost depend on LOCALITY. The longer a predicted category must be kept in WM before the prediction is satisfied, the greater is the memory cost for maintaining that prediction. The greater the distance is between an incoming word and the most local head or dependent to which it attaches, the greater the integration cost.

When a syntactic prediction has been made, a WM cost of one memory unit (MU) is taxed every time a new discourse referent is encountered until the prediction is satisfied. The operational definition of 'new discourse referent' is either introduction of a referent not so far mentioned, or a tensed verb. Because several syntactic predictions may be active

simultaneously, several WM taxation counts may be running simultaneously, consuming WM resources. The main verb is assumed to be cost-free because its existence is taken for granted in every sentence.

SPLT explains the processing difficulties associated with an impressive number of difficult structures, including the unacceptability (I would say: ungrammaticality) of multiple center-embeddings such as the double object relativization (21).

To illustrate, first consider Gibson's examples (23, 24)

(22) The reporter [$_{C\text{-}1}$ who attacked the senator] admitted the error.
(23) The reporter [$_{C\text{-}1}$ who the senator attacked] admitted the error.

In the subject-relativized sentence (22), *who* predicts the occurrence of a predicate and a pronoun gap in the relative clause. When the next word *attacked* is encountered, both predictions are satisfied and no costs incur. *Attacked* next predicts an object but this occurs as the next constituent and therefore no costs incur for this prediction either. The total WM taxation for (22) is therefore 0 MUs.

Next, consider the object relativization in (23). *Who* makes the same predictions as in (22), but the next constituent is the new referent expressed by *the senator*, whereupon both predictions incur a cost of 1 MU, totaling 2M(1) (two predictions having passed one new referent). Next *attacked* resolves the pending predictions and the analysis proceeds as in (22). Thus the correct analysis is made that object relativization is more complex by consuming more WM resources than subject relativization, a fact well established in psycholinguistics.

Now consider Gibson's (made-up) equivalent of (21), sentence (24) with double object relativization:

(24) The administrator [$_{C\text{-}1}$ who the **intern** [$_{C\text{-}2}$ who the **nurse supervised]** had bothered] lost the medical reports.

The syntactic predictions (i.e. the predicate and the relative pronoun gap) of the first *who* will not be satisfied until *had bothered* is encountered, yielding a WM expenditure of 2M(3) MUs, the relevant three crossed new referents pending in WM storage being *intern*, *nurse* and *supervised* (bolded in (24)).

Gibson infers the following generalization "…structures which include a parse state with at least two long unresolved predicted categories in addition to the top-level verb are unacceptable, and those without such a state are usually acceptable. Under the memory cost function assumed here, a 'long' unresolved prediction is one spanning at least three intervening new discourse referents. Thus, sentences whose parses include parse states whose memory cost is 2M(3) MUs or greater are generally not acceptable, while sentences whose parses do not include such a costly parse state are generally acceptable. A reasonable conclusion from this analysis is that linguistic working memory capacity is somewhere around 2M(3) MUs or just below".

Gibson based his analysis on a handful of invented examples. The rest of this paper evaluates Gibson's ACCEPTABILITY LIMIT in the light of my empirical data on multiple center-embeddings. A characterization is also offered of the overall processing complexity of these constructions.

Triple center-embeddings

Of the thirteen observed triple center-embeddings, only one, (25), is clearly below the acceptability limit, by Gibson defined as 2M(3) MUs. (25) consumes only 1M(3) for satisfaction of the prediction at *weil* that C-1 needs a predicate. This prediction is satisfied at the word *verzichtet*, having crossed three new discourse referents, one in each of the embedded clauses (*Mitbewerber*, *angenommen*, *überlegen*). At *angenommen wird* there is a parse state with a cost of 1M(2)+2M(1) MUs, also clearly below the acceptability limit. (Note the use of the plus notation to indicate the sum of differing simultaneous prediction costs.) The consumption of WM resources is low in (25) because all three embedded clauses are short, C-2 contains two pronouns, and C-3 an impersonal passive construction which disposes of its grammatical subject.

(25) Er hat den Preis nur, [$_{C\text{-}1}$ weil ein Mitbewerber, [$_{C\text{-}2}$ welcher ihm, [$_{C\text{-}3}$ wie allgemein angenommen wird,] überlegen ist,] verzichtet hat,] bekommen. (Literal gloss: 'He has the price only, (C-1) because a competitor, (C-2) who over him, (C-3) as is generally presumed, (C-2) is superior, (C-3) gave up, (Main) got.') (Blatz 1896: 1274)

There are two C^3s reaching a maximum of 1M(4), with all prior parse states < 2M(3). Gibson does not discuss instances where only one prediction crosses more than three referents. Assuming for the moment that the effort invested in one syntactic prediction would be equal in WM cost to that of crossing one new referent, we obtain the value 6 for the TOTAL EFFORT invested at Gibson's acceptability limit (2 syntactic predictions * 3 referent crossings = 6). We shall assume that all multiple center-embeddings with a maximal total effort smaller than 6 are below the acceptability limit, in particular 1M(4), 1M(5) and 3M(1), all of which exist, provided they have no prior parse state exceeding 2M(3). Thus three C^3s out of 13 are clearly below the limit, when redefined in terms of total effort = 6.

Sentence (9) is exactly at (or, according to Gibson, perhaps slightly above) the acceptability limit 2M(3), which is reached at the verb *is* in C-1, after crossing of the three referents *riding*, *cycle*, and *road*. In C-3 neither the bleak copula nor the classificatory NP *motor vehicle* were included in the count because C-3 expresses a property, not an independent referent. Note the non-finitenesss of the verbs in C-2 and C-3 and the consequent suppression of two

grammatical subjects by sharing them with the upper clause. There is one more C^3 in the corpus at 2M(3) with an additional parse state at 1M(4):

(26) Der Landvogt ... fand, [$_{C\text{-}1}$ als er, [$_{C\text{-}2}$ von dem, [$_{C\text{-}3}$ was vorgefallen,] benachrichtigt,] in bestürzten Märschen zurückkehrte,] die Stadt in allgemeinen Aufruhr. ('The governor found, (C-1) as he, (C-2) about that, (C-3) which [had] happened, (C-2) notified, (C-1) returned in fast march, (Main) the city in general uproar'. (H. von Kleist, Michael Kohlhaas; Hoffmann-Krayer 1925: 131)

Sentence (8) above requires maximally 1M(6) MUs and is on the same level of processing complexity as those needing 2M(3) MUs when analyzed in terms of total effort.

The remaining seven C^3s are further beyond the acceptability limit. Sentence (7) above and one more claim exactly 2M(4) MUs, one claims 2M(4) with a later parse stage of 1M(5). These sentences were produced by well-known writers and do not intuitively feel (much) more complex than (9, 26), suggesting that 2M(3) MUs is just one point on a more continuous slope of decreasing acceptability. Still more convoluted is the following sentence from von Kleist:

(27) Der Ritter von Malzahn, [$_{C\text{-}1}$ dem der Junker sich als einen Fremden, [$_{C\text{-}2}$ der bei seiner Durchreise den seltsamen Mann, [$_{C\text{-}3}$ den er mit sich führe,] in Augenschein zu nehmen wünschte,] vorstellte,] nötigte ihn ... ('(M) The rider from Malzahn, (C-1) to whom the Junker himself as a stranger, (C-2) who upon his journey (through) the strange man, (C-3) whom he brought with himself, (C-2) to judge by appearance wanted, (C-1) introduced, (Main) forced … (H. von Kleist, *Michael Kohlhaas*; Schneider 1959: 469)

The more verbose the embedded clauses are, and the more full (non-pronominal) constituents they contain, the greater will be the WM expenditure as new referents are crossed. (27) has a parse state peak at *in Augenschein* requiring 1M(5)+2M(4) MUs, where the prediction of the predicate in C-1 (*vorstellte*) has crossed (at least) five referents (it is not always clear what should be counted as a referent, what not), and the predictions of a predicate and subject relative in C-2 have consumed 2M(4) MUs. When the prediction of *vorstellte* in C-1 finally is satisfied, its parse state has risen to 1M(6): the referents crossed are *Junker – Durchreise – Mann – führe – Augenschein – nehmen.*

The three most complex C^3s in my corpus are a Swedish one from 1863 reaching 2M(6), a German one from 1893 peaking at 2M(6)+2M(4) with a later local maximum at 2M(7), and a Danish sentence from a court decision in 1892 containing a maximum of 2M(6)+2M(4) with a later local peak 1M(11), cf. examples (3, 12, 13) in Karlsson (2007b). Such monster sentences are of course incomprehensible.

The conclusion of the analysis of C^3s must be that few of them, only three, are below Gibson's acceptability limit. If the limit reflects a foundational WM restriction, this corroborates the marginality of C^3s as a structural option, already expressed in (14). But the extant C^3s rather seem to populate a gradual slope, where the value 2M(3) MUs does not stand out as being of particular significance.

Double center-embeddings

The 104 C^2s in my corpus distribute themselves over WM cost as shown in Table 1. Columns 1a-b give the WM costs and numbers of those C^2s that clearly are below Gibson's limit 2M(3) MUs (total effort less than 6). Columns 3a-b lists the instances which are above the acceptability limit with a total effort equal to or greater than 6.

Table 1: Working memory cost in 104 C^2s.

1a	1b		2a	2b	Total
Cost	**N**		**Cost**	**N**	
M(0)	1		1M(6)	4	
1M(1)	9		1M(7)	1	
1M(2)	12		1M(8)	2	
1M(3)	10		2M(3)	11	
1M(4)	5		2M(4)	6	
1M(5)	3		2M(5)	1	
2M(1)	13		2M(6)	1	
2M(2)	17		2M(9)	1	
3M(1)	4		3M(2)	1	
			3M(3)	2	
Sum	74			30	104
%	71			29	100

More than two thirds of the C^2s are below the limit and many of them are far from causing overflow in working memory. Here is an assortment, listed according to growing complexity, of those C^2s that are easiest to process and understand, with the WM cost indicated at the end in angular brackets.

(28) The girl ... [$_{C\text{-}1}$ who was clothed in the tightest-fitting pair of slacks [$_{C\text{-}2}$ I had ever seen on a woman] and a sweater [$_{F\text{-}2}$ that showed everything [$_{F\text{-}3}$ there was]]] wanted to be sociable. [M(0)]

(29) We yet looked forward to a time ... [$_{F\text{-}1}$ when the rule [$_{C\text{-}2}$ that they [$_{C\text{-}3}$ who do not work] shall not eat,] will be applied not to paupers only. [1M(1)]

(30) It's ironic [$_{F\text{-}1}$ that I'm here, [$_{F\text{-}2}$ where the man [$_{C\text{-}3}$ the trophy [$_{C\text{-}4}$ I won] is named after] coached. [1M(2)]

(31) The reason [$_{C\text{-}1}$ why this question of [$_{C\text{-}2}$ when the copy was made] is of some interest] is that ... [1M(3)]

(32) He knows ... [$_{F\text{-}1}$ that, for example, [$_{C\text{-}2}$ whereas in 1908 the proportion of his students at Leeds [$_{C\text{-}3}$ who were drawn from within 30 miles] was 78 %,] it was, by 1955, reduced to 40 %. [1M(4)]

(33) Laughland's assertion [$_{C-1}$ that the presence of Delors – 14 years old [$_{C-2}$ when the war began –] in the Compagnons de France, the Vichy youth movement, meant [$_{F-2}$ that he supported fascism]] is ridiculous. [1M(5)]

(34) The two most difficult skills [$_{C-1}$ that everyone [$_{C-2}$ I know] has to learn when they join a team] are… [2M(1)]

(35) All the concern [$_{C-1}$ which he [$_{C-2}$ to whom it belongs by adoption] has in the matter] is the being ... [2M(2)]

(36) But the general principle [$_{C-1}$ that every thing [$_{C-2}$ to which such and such sensation belongs,] has such and such a complicated series of predicates,] is not one determined by reason but… [3M(1)]

In contradistinction to C^3, C^2 is obviously a well-established even if rare construction type especially in written language: there is no question of the grammaticality and acceptability of (28-36) even if it is clear that overall acceptability has a tendency to decrease as the number of constituents pending in WM and the number of new referents crossed increases.

Note that there even are C^2s like (28) that invoke no WM cost at all. This situation is possible in (28) because the subject and predicate of C-1 (*who was clothed*) are immediately available and therefore the do not need to be entered as pending predictions in WM. The predicate of C-1 predicts the occurrence of an adverbial prepositional phrase, but it too (*in the tightest-fitting pair of slacks*) is completed immediately, as the first part of a coordinated construction. C-2 is beneficially inserted before the second, optional part of the coordinated construction in C-1 and therefore does not tax WM at all. – (The C-3 of (7) is also inserted at a coordination junction, corroborating conclusion (18) that multiple center-embedding is preferred at natural syntactic breaks.)

The following sentences exemplify those 30 sentences (29 %) of Table 1 that are at or beyond the acceptability limit, consuming 1M(6) or 2M(3) MUs or more. The examples are listed according to growing complexity.

(37) For the remainder of his industrious life (apart from during the second world war [$_{C-1}$ when he worked in the Ministry of Information [$_{C-2}$ – where he was banished to Belfast [$_{F-3}$ for being lazy and unenthusiastic –]] and the Auxiliary Fire Service)] Quennell ... [1M(6)]

(38) And in particular [$_{C-1}$ when the motives [$_{C-2}$ which are applied] are of the nature of those [$_{F-2}$ which result from a change [$_{f-4}$ made in the condition of the body,]]]] the power may be said to … [1M(8)]

(39) Neither, however, [$_{C-1}$ as their critics and all of those [$_{C-2}$ who subsequently complained about their assault on Heath] always stress,] felt moved to resign. [2M(3)]

(40) The occasion [$_{C-1}$ on which in the nation [$_{C-2}$ of whose language I am writing] the word *repugnancy* has been most frequently made use of] is that where ... [2M(4)]

(41) A number of speeches [$_{C-1}$ into which a great deal of thought and preparation on a level a great deal higher [$_{C-2}$ than is common in modern politics] have gone] are not reported at all ... [2M(5)]

(42) Es wird allgemein angenommen, [$_{F-1}$ dass die Militärs, [$_{C-2}$ die das Land dreizehn Jahre lang mit Unterschiedlichem Erfolg und — mit Ausnahme Murtala Muhammeds, [$_{C-3}$ der erst sieben Monate an der Macht war, [$_{F-4}$ als er im Februar 1976 ermordet wurde]] — ohne Popularität zu erlangen geführt haben,] von sich aus eine Rückkehr an die Macht nicht anstreben. 'It is normally surmised (F-1) that the soldiers (C-2) who ruled the country thirteen years with variable results and – with the exception of Murtala Muhammed, (C-3) who first was seven months in power (F-4) until he was murdered in February 1976 – without achieving popularity, do not themselves strive for a return to power.' [2M(9)]

(43) For an analysis of the possible modifications [$_{C-1}$ of which the pathological termination of an act [$_{C-2}$ which is not according to law] are susceptible] we have therefore only to ... [3M(2)]

(44) (Swedish:) Helt säkra på [$_{C-1}$ vad blandningen, [$_{C-2}$ som de insjuknade har druckit] består av,] var läkarna inte.] '(M) Quite sure of (C-1) what the mixture, (C-2) that the patients had drunk (C-1) consisted of, (Main) the doctors were not'. [3M(3)]

Table 2 displays the data of Table 1 recounted in terms of total effort.

Table 2. Data of Table 1 recalculated in terms of total effort.

Total effort	**N**
0	1
1	9
2	25
3	14
4	22
5	3
6	16
7	1
8	8
9	2
10	1
10+	2
Sum	104

Recall Gibson's definition of the acceptability limit: "… linguistic working memory capacity is somewhere around 2M(3) MUs or just below". Table 2 shows that there are no less than 16 instances of 2M(3) and its equivalents of a total

effort of 6. These instances cannot all be declared unacceptable by intuition alone. This suggests at least that the acceptability limit rather is above than below 2M(3) MUs and its equivalents.

Discussion

The analysis of C^3s and C^2s has shown that the conjecture of a demarcation line at 2M(3) MUs, or slightly below, between acceptable and unacceptable multiple center-embeddings does not find clear support in real language data drawn from genuine written texts or, rarely, from natural spoken discourse. If there is such a demarcation line, it is rather above than below 6 total effort units. But most likely, the overall data speak in favor of a cline of asymptotically decreasing complexity.

There might be systematic flaws in the design of the procedure counting MUs. For example, the Swedish sentence (44) has a WM cost of 3M(3) which is huge. All ten native informants (including myself) I have consulted on the acceptability of (44) confirm that there is nothing weird about this sentence, which appeared in 2001 in the main Swedish newspaper of Finland, *Hufvudstadsbladet*. It is perfectly grammatical, acceptable and understandable. Its WM expenditure is high just because the prediction of its main clause subject is satisfied only after the doubly center-embedded relative clauses have been passed. That is, the prediction of a postposed main clause grammatical subject (here, *läkarna* 'doctors') turns out to be overly costly. The model needs revision.

A similar problem occurs in sentences with an initial modal or frame adverbial and a postposed grammatical subject, like (38, 39). The late grammatical subject causes the WM cost to become unrealistically high.

Overall, the data of this paper are in good conformance with current theories of the nature of working memory, e.g. Cowan's (2000, 2005) theory of the storage limit on WM being around four chunks, or the well-known capability of humans to be able to simultaneously register some four elements in the focus of visual attention. Recall that even C^2 is next to non-existing in spoken language (15). Sentence (30) above is one of the few documented ones from spoken language. Its WM cost is only 1M(2), far below Gibson's acceptability limit. Of course one should not let the most extreme instances of written language, such as (44), define what the bottom line of (spoken) language WM consumption is.

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