Quantifier scope: a formal and experimental study

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This work is part of a general research program, whose aim is to confront the predictions of linguistic formalisation to actual human processing mainly for lexical, syntactic and above all semantic issues, excluding as much as possible the interference with pragmatics. Examples of questions to be address are the following: Are there preferred readings? Is a sentence complex to interpret? Which linguistic ingredients are responsible for its complexity?

We present here a semantic claim about quantifier scope taking, together with an experiment (described below) that we designed to test this claim, and which actually justifies our claim.

On the formal side, we view quantification with Hilbert's epsilon terms as in the type-theoretical computational semantic framework that we introduced recently [1]. Epsilon terms, that can be compared with choice functions and opposed to generalised quantifiers, denote generic individuals: they provide a logical structure with *in situ* quantification that follow the syntactic structure and thus naturally express underspecification. This is quite adequate to our study which involves variants and reformulations of sentences with two quantifiers.

As opposed to apparently related work like [2] we clearly focus on the interpretation of the utterance: the choice of the lexical items, the syntactic structure, and the semantic interpretation itself. As such, we tried to minimise the influence of reasoning tasks, computational issues and world knowledge — although the observation of the semantic interpretation requires some of these.

The precise task to which we applied our view in this paper is quantifier scope disambiguation in universal-existential double-quantified sentences. These are sentences such as "An identification number is given to every student". It has two readings, and common knowledge, syntax and the choice of the quantifying determiners influence its disambiguation. Here we focus on the determiners expressing universal quantification *chaque* and *tous les*, and we observed they do not perfectly match English quantifiers: *tous les* resembles *all* and *every*, while *chaque* rather corresponds to *each* (although *chacun* corresponds to *everyone*). For the existential quantifier, its simplest expression *un(e)* — the indefinite article (*a*) — is homonymous with the numeral *un(e)* (*one*). Even though work on such sentences has been done in English like [3], the equivalent constructions remain understudied in French and furthermore our view on the issue is slightly different.

Our aim is to look at the comprehension of sentences in terms of visual situations. To prevent any effect of pragmatic inference on sentence comprehension, items are made as neutral as possible : squares and circles. The computational aspects are also minimized by giving a very little number of items (3 of each), and asking a response time as short as possible. We also tried to prevent any natural left-to-right lecture of images by positioning the items horizontally. We observed the reaction time, and recorded eye gaze to have a look at internal comprehension processes.

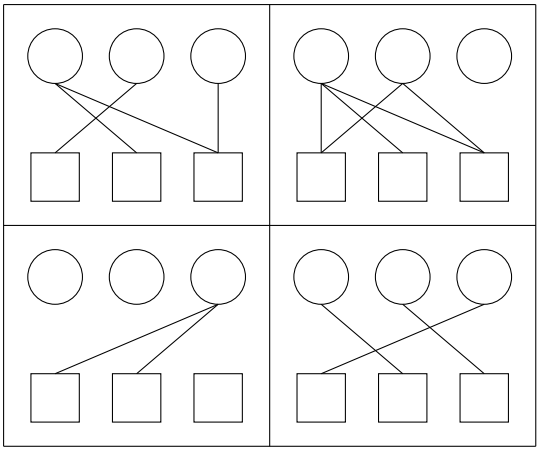


Figure 1. Exemple of visual stimulus

Our material thus resulted in figure combinations as the one presented in Fig. 1 paired with auditory-presented sentences of the form "$[U/E]$ carré est relié à $[E/U]$ rond " ($[U/E]$ square is connected to $[U/E]$ circle), existential (E) quantifier always being *un* and universal (U) quantifier being either *chaque* (U_{chaque}) or *tous les* ($U_{tous\ les}$). Each of the four figures shown on the stimulus represents a lecture (here, from left to right and top to bottom, $U_{tous\ les} \succ E$, $E \succ U$, a lure item, and $U_{chaque} \succ E$)[1].

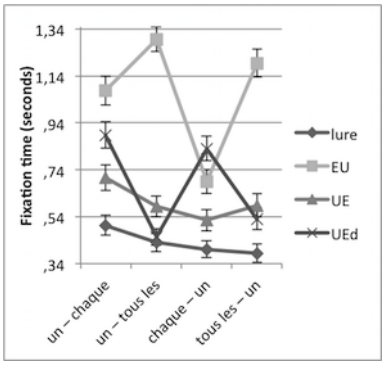
Then we collect interpretation (figure choice), reaction time, and eye gaze. All this give us information on the computed meaning of the sentence, its complexity, and possible distractors from target.

Our results (see Fig. 2) confirm some theoretical assumptions about general phenomena influencing quantifier scope disambiguation, such as linear order in sentence or lexical

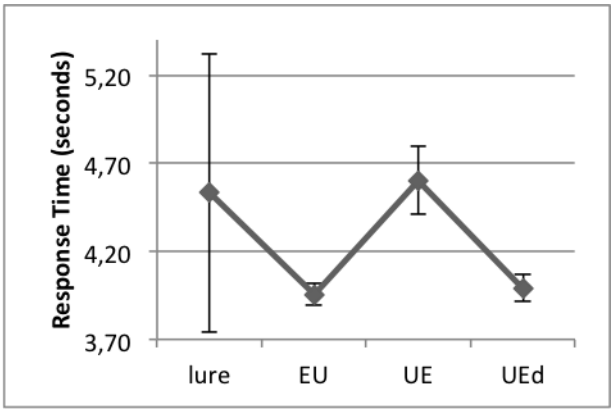
[1]We use here the convention symbol $\succ$ as corresponding to "takes wide scope on"

			click			
			EU	UE	UEd	Total
sentence	un - chaque	Count	316	55	217	588
		Expected Count	361,9	50,8	175,3	588,0
	un - tous les	Count	502	38	41	581
		Expected Count	357,6	50,1	173,2	581,0
	chaque - un	Count	176	53	304	533
		Expected Count	328,1	46,0	158,9	533,0
	tous les - un	Count	418	52	122	592
		Expected Count	364,4	51,1	176,5	592,0
Total		Count	1412	198	684	2294
		Expected Count	1412,0	198,0	684,0	2294,0

(a) Sentence-Choice crosstable



(b) Fixation times across sentences



(c) Reaction time across choices

Figure 2. Main results, figures of fixation times across sentences and reaction times across sentences are not shown here but lead to same conclusions.
Error bars on plots represents 95% confidence intervals, thus statistical significance is achieved whenever error bars do not overlap (more precise statistical data available on demand).
A Pearson's χ^2 analysis showed a significant effect on the distribution of choices across sentences.

realization of quantifiers, confirming part of the scale of [4]. Indeed, *chaque* has been shown to be a stronger quantifier than *tous les*, whith respect to taking scope — this is probably related to their different meanings see e.g. [3].

Furthermore, our results suggest that *un* should take wide scope on *tous les* but not on *chaque*, as it is suggested by the end of [4]. More precisely, *un* interferes more with *chaque* than with *tous les*. It thus seems to be the case that *un* is closer to *chaque* with respect to taking scope over different quantifiers than to *tous les*, giving a greater precision to binary relations between quantifiers.

These results are concordant with Default theory see e.g. [5] and Grice's Maxims of Quantity, and opposed to Relevance theory [6]. Indeed, while Relevance theory expect a logical reading, thus no difference between the logically equivalment universal terms (*chaque* and *tous les*), they interact significantly differently depending on the context. This suggest that the use of one rather than the other is informative for the addressee.

Finally, our study presents a good start in this domain, providing precise knowledge about quantifier scoping. It also paves the way to further investigations to test the relation between formal semantics and actual human processing, in particular as regards reading preferences and the complexity of ambiguous sentences.

References

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