INTRODUCTION

There are evidences accounting for an organization in subcomponents of linguistic parser, but remain to clarify how and when these components interact. Roder (2000) showed that reading times and grammatical acceptability vary as a function of syntactic complexity, operationalized through variations by the Canonical phrasal structure, not only in Real sentences, but also in sentences without semantic content (Jabberwocky). Specifically, judgments of syntactic acceptability were perfectly comparable to Real speech and Jabberwocky, with no semantic involvement. Aim of our experiment was to evaluate more precisely, through eye movements' analysis, the impact of syntactic complexity and lexical information on reading process in Italian.

METHODS

Materials

Stimuli consisted of 208 declarative sentences, each composed of nine words that varied for the syntactic complexity and for the semantic content. There were 104 sentences composed by real words (Real) and 104 sentences obtained from the former by swapping the letters position inside each content word (Jabberwocky). In Jabberwocky sentences, function words and morphological suffixes (verb tense and gender and number agreement) were the same of Real sentences in order to allow a comparable syntactic processing even for Jabberwocky. Half of the sentences were constructed with a canonical Subject-Verb-Object order (Canonical); the other half were obtained by exchanging constituent's order, thus forming less frequent (Unusual) thought acceptable sentences. Four sets of sentences were thus obtained, that is Real sentences with a Canonical (RC) or Unusual (RU) structure, and Jabberwocky with a Canonical (JC) or Unusual (JU) structure. Each sentence was presented on a single line in 22-point Arial font as 1024×768 image. Stimuli were arranged into two lists A and B, each containing 26 sentences of each type for a total of 104 sentences for each list. All words were balanced for number of characters, so that any word exceeds 11 characters in length, and frequency of use. Sentences were was also balanced for lenght, in order to exclude differences in reading times due to the difference in the total number of characters.

Procedure

Sixteen health subjects (8 males; mean age ± SD = 26.7 ± 2.1 years) participated in the experiment. Eye movements were recorded by an infrared video-based eye-tracking device (RK-826PCI pupil/corneal tracking system; ISCAN, Burlington, MA). Before the experiment started, readers read a set of instructions that told them to read at their normal rate and to comprehend the sentences as well as they could. Subjects were seated in a comfortable chair in front of a 17" computer monitor that was positioned on the fronto-parallel plane at a distance of 57 cm. Their heads were stabilized by means of a chin and a head rest. At the beginning of each session, gaze position was calibrated using a five points calibration procedure. Every trial began with the presentation of a black cross on the left of the screen (dimension: 1.25°×1.25°; position: -15° of visual angle) that participants were required to fixate. After 2500 ms the experimental sentence was presented. After reading the sentence and pressing the spacebar to signify completion, the sentence disappeared and the question relating to that sentence appeared, requesting subjects to judge the acceptability of syntactic structure using as reference a 5-point Likert scale. There were four recording sessions, each composed of 26 trials, for a total of 104 trials. Both the order of trials within a session and the order of sessions were randomized.

Data analysis

We examined Acceptability Judgment and standard eye movement measures (Rayner 1998): First Pass Reading; Total Reading Time; Regressions out of a region. Sentences were divided into four regions, each containing a single constituent. We conducted separate ANOVAs for participants and items with SEMANTIC CONTENT (Real Vs Jabberwocky), SYNTACTIC STRUCTURE (Canonical Vs Unusual) and REGION as within-subjects factors.

RESULTS

Total reading time

The ANOVA revealed high significant main effects of all the factors: SEMANTIC CONTENT ($F1_{(1,15)}$=56.65; $F2_{(1,51)}$=37.82; ps<0.001), with longer reading time for Jabberwocky (M=883) compared to Real (M=602) sentences; SYNTACTIC STRUCTURE ($F1_{(1,15)}$=19.99; $F2_{(1,51)}$=21.25; ps<0.001), with total reading time longer for Unusual (M=777) than Canonical (M=709) sentences; and REGION ($F1_{(1,15)}$=34.45; $F2_{(1,51)}$=29.84; ps<0.001). Post-hoc analysis were conducted using Tukey's HSD test (p<0.05). The ANOVA also revealed the significance of a two-way interactions of prime theoretical interest. A significant CONTENT×STRUCTURE interaction was observed ($F1_{(1,15)}$=13.45; $F2_{(1,51)}$=19.84; ps<0.005; see figure 3). Post-hoc analysis showed that all the pair-wise comparison were significant, revealing that the syntactic cost in reading Unusual sentences (calculated as difference between Unusual and Canonical reading times) is higher for Real (105 ms) compared to Jabberwocky condition (31 ms). Also the CONTENT×REGION and STRUCTURE×REGION interactions reached statistical significance (all Fs>10; ps<0.001). Given that in sentences with different syntactic structures regions are composed by different syntagms, we run two separate ANOVAs for Canonical and Unusual sentences. In both ANOVAs, the main effects and the CONTENT×REGION interaction resulted significant (all Fs>4.36; ps<0.01). Specifically, in Canonical condition the total reading times were higher for the last region (i.e., dative/genitive syntagm; M=920 ms) and lower for the third region (i.e., object syntagm; M=550 ms), and the CONTENT×REGION interaction is explained by the fact that the semantic cost in reading Jabberwocky sentences (computed as difference between Jabberwocky and Real reading times) was higher for the first and second regions (i.e., subject and verb; 390 and 349 ms, respectively; see figure 4a). On the other hand, in Unusual condition the total reading times for the last region (i.e., verb; M=1027 ms) were higher than these for the first region (i.e., dative/genitive syntagm; M=814 ms), which in turn were higher than the reading times for the other two regions (i.e., object syntagm and subject; M=613 and 653 ms, respectively). Once again, the CONTENT×REGION interaction in Unusual sentences revealed that the semantic cost in reading Jabberwocky sentences was higher for the first and second regions (287 and 270 ms, respectively).

First-pass reading time

The analysis conducted on first-pass reading times lead to comparable results, except for the CONTENT×STRUCTURE interaction. Indeed, post-hoc analysis revealed that the first-pass reading times for Unusual and Canonical sentences in Jabberwocky condition did no longer differ (M=721 and 745 ms, respectively), whereas in Real condition the first-pass reading times were reliably higher in Unusual (M=475 ms) than Canonical (M=415 ms) sentences.

Regression out

The ANOVA revealed significant main effect of STRUCTURE ($F1_{(1,15)}$=8.35; $F2_{(1,51)}$=16.71; ps<0.05), with a larger number of regression for Unusual (M=5.4) than Canonical (M=2.1) sentences, and REGION ($F1_{(1,15)}$=34.45; $F2_{(1,51)}$=29.84; ps<0.001), with more regression out of last region (M=4.8) than the other two regions (M=3.4 and 3.2 for the second and third region, respectively).

The ANOVA also revealed the significance of all the two-way interactions. We found that participants made a larger number of regression out for Real than Jabberwocky sentences, but only in Unusual condition (CONTENT×STRUCTURE interaction: M=6.3 and 4.5, respectively; $F1_{(1,15)}$=7.97; $F2_{(1,51)}$=13.51; ps<0.05; see figure 6a) and in the last region (CONTENT×REGION interaction: M=5.4 and 4.2, respectively; $F1_{(2,30)}$=3.4; $F2_{(2,102)}$=6.02; ps<0.05; see figure 6b). Moreover, the STRUCTURE×REGION reach the statistical significance ($F1_{(2,30)}$=3.98; $F2_{(2,102)}$=5.64; ps<0.05; see figure 6c), indicating that regression out of the last region are more (M=6.9) than the other two region (Ms=4.7), but only for Unusual sentences.

Acceptability judgment

The reapeated-measure ANOVA carried out on acceptability judgment with STRUCTURE and CONTENT as within subjects factors revealed the high reliability of both the main effects and the CONTENT×STRUCTURE interaction. Post-hoc analysis showed that all the pair-wise comparison were

significant, showing that participants judged as more syntactically acceptable the RC sentences (*M*=4.7), followed, in order, by JC (*M*=2.9), RU (*M*=2.7) and JU (*M*=1.6) sentences.

DISCUSSION

Acceptability ratings partly confirmed Roeder's results because they indicate that subjects are able to judge also the structure of meaningless sentences. Total Reading Times (RTs) showed that syntactic cost is higher in Real sentences compared to Jabberwocky due to difficulty in integrating lexical information in unusual syntactic structures. For first pass analysis, we conducted a separate ANOVA for different structures, finding same main effects discussed for RTs, but no significant differences in Jabberwocky with different structure, as for the interaction between semantic content and syntactic complexity. We suppose that the unpredictability for non-existing words causes the increase of RTs even for the first pass, regardless of the syntactic structure. We observed an interaction between structure and content information on regression movements. In Unusual sentences more regressions were made in Real sentences. Again, syntactic cost is higher when lexical information must be integrated. The interaction between syntactic structure and region position on regressions, suggest that in Unusual sentences more regressions are made than in Canonical sentences, especially from the last region (verb or the pseudo-verb) that disambiguate the whole syntactic structure. As to the interaction between semantic content and region we found a significant effect on regressions in Real sentences from the last region regardless of syntactic structure. This can be interpreted as semantic integration cost on reanalysis processes (Friederici, 2002). Briefly, although is possible to dissociate syntactic and semantic computing in real language processing, reading times result faster when syntactic and lexical integration is possible, and syntactic cost is higher in sentences formed by Real words, confirming the interaction between syntax and semantics.

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