Adapting the visual world paradigm to sign languages: asymmetries in LSF relative clause processing

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Abstract

This paper presents the first cross-modal investigation of subject and object relative clause processing using the Visual World Paradigm (VWP) for written and signed stimuli. We adapt the original audio-visual VWP paradigm to a visual-only display to make it suitable to the investigation of sign languages. We test the viability of this adaptation on an already well-studied population: French native speakers. In this first experiment, we use videos displaying written French stimuli to see if participants are able to both look at the stimuli and perform the VWP task of fixating one of two pictures. Crucially, we show that this new visual-only display replicates the results obtained with the original audio-visual design from Pozniak (2018): in both paradigms subject relative clauses are easier to process than object relative clauses in French. This first experiment confirms the reliability of the visual-only VWP. We then present the innovative use of the Visual (only) World Paradigm to investigate for the first time asymmetries in the processing of subject and object relative clauses in a sign language, French Sign Language, with signed sentences as stimuli. The results offer in depth insights both on the linguistics of sign languages and on psycholinguistic research methods.

Keywords: Eye-tracking, Visual world paradigm, French Sign Language, subject and object relative clause processing, French

1. Introduction

From a typological standpoint, relative clause accessibility varies greatly depending on the position of the gap involved. Object relative clauses (see 2) are found less frequently across languages than subject relative clause (cf. 1), as captured by Keenan & Comrie (1977)'s accessibility hierarchy.

(1) ... the **cat** that ___ kicked the dog.

(2) ... the **cat** that the dog kicked ___.

From a psycholinguistic standpoint, the two constructions also present asymmetries. Subject relative clauses are found to be easier to process than object relative clauses in many languages (King & Kutas 1995, Diessel 2004, Hawkins 2004, Constable et al. 2004, Hale 2006, Hale 2016, Stromswold et al. 1996 Traxler et al. 2005 a.o.). The universality of this asymmetry is however debated within the scientific community (Gibson 2000, Yun et al. 2015 a.o.). It indeed varies in intensity across — and within — languages depending on factors such as word order, relativization strategies, context, as well as semantic and pragmatic factors (Gennari & MacDonald 2008, Gennari & MacDonald 2009, Mak et al. 2006, Mak et al. 2008, Roland et al. 2012 a.o.). When looking only at syntactic factors, the subject relative clause advantage is particularly robust in SVO languages with postnominal relative clauses such as English and French, in which the head NP and the gap are both linearly and structurally closer in subject relatives than in object relatives (cf. 1-3).

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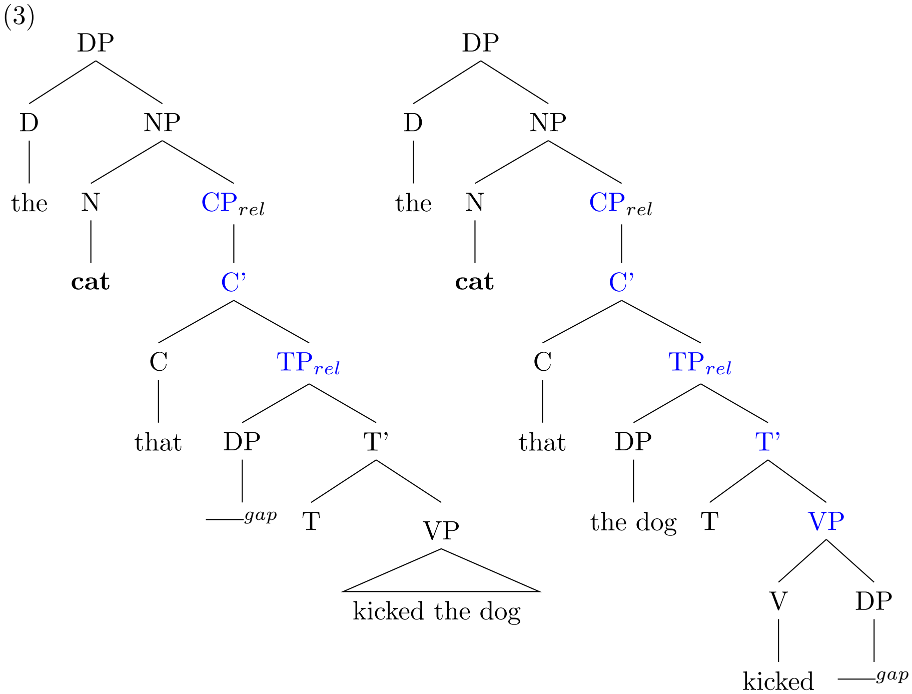

Subject Relative Clause *Object Relative Clause*

While subject and object relative clause processing has been at the center of a large number of studies, varying in their methodologies and in the languages studied, there is one whole type of languages that has been left in their blind spot: sign languages.

Despite being a rather young field of linguistic, sign language studies have concentrated very early in their history on the description of relative clauses and subordination (see Liddell 1978, for American Sign Language). This interest for complex constructions came as a necessity since sign languages have long been stigmatized as rudimentary communication systems (Thompson 1977, Friedman 1991). Demonstrating that sign languages are full fledged languages obeying the same principles as all natural languages can greatly impact sign language recognition and Deaf people's language rights.
Other scholars in the field, on the other hand, consider that looking for structures in sign languages is an attempt at superimposing spoken languages standards on sign languages (SL). For tenants of this approach like Bouchard (1996),

the ever growing literature documenting relative clauses in various sign languages (American SL; Liddell 1978, Liddell 1980, Galloway 2011, Italian SL; Cecchetto et al. 2006, Branchini & Donati 2009, Donati & Branchini 2012, Brazilian SL; Nunes & de Quadros 2005, German SL; Pfau et al. 2005, Happ & Vorköper 2006, Japanese SL; Penner et al. 2019, Hong Kong SL; Tang & Lau 2012, LI 2013, Turkish SL; Kubus 2011, Catalan SL; Mosella Sanz 2011 and French SL Hauser 2016, Hauser & Geraci 2017) does not constitute evidence in favor of shared underlying structures between spoken and signed languages as much as it imposes a wrong spoken-centric view on languages.

In this agitated context, investigating the processing of relative clauses in sign languages represents an important step forward in the debate: if a structure displays the same cognitive bias in spoken and in sign language then it is sound to consider it as being shared between the two modalities. For this reason, we choose to analyze French Sign Language (LSF) relative clause processing by adapting the Visual World Paradigm (VWP) that has been successfully used to investigate the processing of spoken language for more than 25 years (Tanenhaus et al. 1995).

In their study of relative clauses, Hauser & Geraci (2017) identified both subject (4) and object (5) relative clauses in LSF.[1][2]

(4) IX-1 PRÉFÈRE HOMME [$\overset{\text{rel}}{\overline{\text{PI}}}$ ___ CARESSE CHIEN] LSF
IX-1 PREFER MAN RELP PET DOG
'I prefer the man who pets the dog.'

(5) IX-1 PRÉFÈRE CHIEN [$\overset{\text{rel}}{\overline{\text{PI}}}$ HOMME CARESSE ___]
IX-1 PREFER DOG RELP MAN PET
'I prefer the dog which the man pets.'

[1] In the following examples, we follow usual glossing conventions: small capitals gloss manual signs, while non manual markers and their extension are indicated through a line above the manual signs. Pointing pronominals are glossed IX and their reference is indicated through coindexation.

[2] The non-manual markers glossed as 'rel' are: raised eyebrows, upper body orientation towards the head noun and mouthing of the relative pronoun 'PI'.

Since LSF uses postnominal externally headed relative clauses just like English and French, we make the hypothesis that subject relative clauses are also syntactically easier to process than object relative clauses in this language. To ensure maximal comparison across languages and modality, we adopt and adapt Pozniak (2018)'s protocol that was used to test asymmetries between SRC and ORC in Mandarin Chinese, Cantonese, English and French.

The paper is organized as follows; Section 2 presents the methodological challenge of turning an audio-visual protocol into a visual-only design and the study we carried out in French to test whether the adaptation still captures the asymmetry in favor of SRC found by Pozniak (2018) through the audio-visual protocol. Section 3 presents the results of our investigation of relative clause processing in French Sign Language and Section 4 is a general discussion of the results found in these two experiments.

2. Adapting eyetracking protocol to a visual-only design

Pozniak (2018), on which this study is based, used a typical visual world paradigm (VWP) with pictures from Knoeferle et al. (2003), which have been validated across multiple experimental designs (see Pozniak 2018 or Knoeferle et al. 2003 a.o.).

The VWP, as applied in Pozniak (2018), initially involves two sensory modalities: two pictures are displayed on a screen (visual modality) while a recorded sentence is played on earphones (auditory modality). Crucially, sounds and pictures are displayed simultaneously, so that participants are free to look at the pictures while listening to the sentence. Their eye movements are captured with an eye tracker and are then analyzed as a reflex of the ongoing processing/comprehension of the sentence.

More specifically, Pozniak (2018) conducted an eye-tracking experiment using the visual world paradigm in French (as well as in Mandarin Chinese, Cantonese Chinese and English). As for the experiment in French, participants were looking at two pictures (see Figure (1)) on a computer screen while listening to French spoken sentences including either subject (6) or object (7) relative clauses[3]. One picture was compatible with a subject relative clause interpretation (the princess in the picture draws the fencer) and the other one was compatible with an object relative clause interpretation (the fencer in the picture draws the princess). In this experiment, participants'task was to find the right picture, meaning the picture that was compatible with the sentence they listened to.

Figure 1: Example of pair of pictures used in Pozniak 2018

(6) Subject relative clause

Prière de trouver la princesse correcte, c'est-à-dire la belle princesse [qui dessine l'escrimeur] sur l'image.

'Please find the correct princess, that is to say the beautiful princess [that the fencer draws] on the picture.'

[3] Pozniak (2018) also manipulated the position of the subject in object relative clauses. For clarity purpose, since we did not manipulate the subject position in our study, we will not mention this in further details in our paper.

(7) Object relative clause

Prière de trouver la princesse correcte, c'est-à-dire la belle princesse [que l'escrimeur dessine] sur l'image.

'Please find the correct princess, that is to say the beautiful princess [that the fencer draws] on the picture.'

In this paradigm, more and earlier fixations on the correct picture are taken as evidence for easier processing. SRC in French were found to be easier to process than ORC.

We decided to adapt Pozniak (2018)'s audio-visual protocol to a visual-only protocol, the rationale of which could then be used to investigate the processing of sign languages. To check whether such an adaptation would not alter the purpose and efficiency of the original design, we started by conducting an experiment with a visual-only design with French native speakers, in order to find out whether the SRC advantage found for French native speakers replicates in this paradigm. The main objective for this first experiment was to create a test of the change of modality to "visual only" in the VWP and a baseline for a second, separate experiment, with LSF stimuli to investigate relative clause processing in this language. In what follows, we present the first experiment on French and then the one investigating LSF relative clauses.

2.1. Visual-only French experiment : design

2.1.1. Material and variables manipulated

The protocol includes 24 items and 25 fillers as well as a training phase made of a mix of 8 additional items/fillers, whose results were excluded from the analysis. The independent variable was relative clause type (subject/object). Position of the picture was counterbalanced, so were the items, following a two by two design (Latin square). The complete list of items can be found in the associated OSF (Foster & Deardorff, 2017) repository (Materials section `https://osf.io/67efy/?view_only=9b97b23fd5ac4a82b6e82be140e25000`).

Just like in the original design, participants saw two competing pictures: one corresponding to a subject relative interpretation (*'the princess that draws the* *fencer'*), and the other one corresponding to an object relative interpretation (*'the princess that the fencer draws'*). Contrary to the original design though, the stimulus displayed was a sentence written in French and not an auditory stimulus. The sentence was parallel to the original design and was divided into seven frames that appeared one by one (every two seconds) on the screen below the pictures.The division of the written stimuli is illustrated in Table 1 for subject relative clauses and Table 2 for object relative clauses.

Merci de trouver Please find	la bonne princesse the right princess	donc so	la belle princesse the beautiful princess	qui that	dessine draws	l'escrimeur. the fencer.

Table 1: Example of a presentation of a sentence for SRC divided into seven frames.

Merci de trouver Please find	la bonne princesse the right princess	donc so	la belle princesse the beautiful princess	que that	l'escrimeur the fencer	dessine. draws.

Table 2: Example of a presentation of a sentence for ORC divided into seven frames.

To determine the right pace between frames, we conducted a pilot study on 8 participants. We started by testing a timespan of 1 second but stimulus presentation turned out to be too fast to allow for simultaneous reading and inspection of the pictures. We then separated frames by two seconds, which was the duration we finally adopted as it gave enough time to participants to perform the task correctly. Therefore, sentences were split up into seven frames that stayed on the computer screen for two seconds each.

Stimuli were counterbalanced across conditions, meaning that for a single picture, half of the participants saw a SRC stimulus, while the other half saw an ORC. Similarly, for every single item, the position of the correct picture was counterbalanced such that, for half of the participants, the correct answer was on the right (whether a SRC or a ORC) and for the other half it was on the left. This is illustrated in Figure 2.

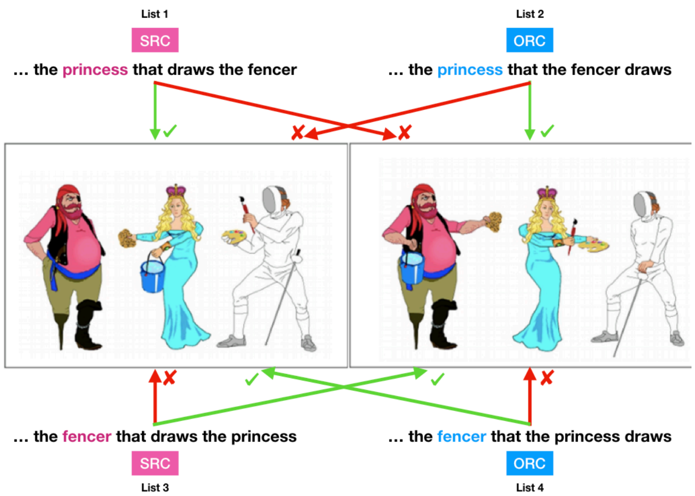

Figure 2: Example of the four alternatives presented across the four lists of items.

This results in four different lists containing the same number of SRC on the right, SRC on the left, ORC on the right, and ORC on the left and each list displaying the item pictures only once. This design, as shown in Figure 2, avoids having always the correct answer in one position, and possible effects of character saliency.

Items are fully randomized with fillers, which are the same across all four lists. Fillers are such that the two alternatives are simple pictures comparing objects or animals, as can be observed in Figure 3.[4]

[4]Given the simplicity of this task, we decided to exclude participants performing lower than 70% on fillers.

[Video stimulus] "Please find the correct picture, that is to say the picture showing a dog."

Figure 3: Example of a filler.

Finally, all trials are introduced by a screen showing a context sentence presenting, from left to right, the characters which will appear in the following item/filler (see 8).

(8) a Context Item: Here are two pictures, both with a pirate, a princess, and a fencer.

b Context Filler: Here are two pictures; a dog and a boot.

These contexts help participants to identify faster each character within the item/filler pictures, and it also allows each character to be equally salient in the context.

The experiment involves three constitutive steps (Instructions, practice, and experiment), with a time break in the middle of the experiment (i.e. after 25 trials) to allow participants to rest and refresh.

In our need to change the protocol to a visual-only display, we decided to separate the screen vertically into two spaces: the upper space was used to display the competing pictures and the lower space was used to display the video of the written sentence. We positioned pictures on the two sides of the screen while the stimulus was displayed in the center to allow maximal differentiation of the three zones (see Figure 4). Each element (i.e., the two pictures and the stimulus) was coded as an Area of Interest (AOI).

Figure 4: Illustration of the visual-only display for French participants.

2.2. Procedure

Eye fixations were recorded with the Eyelink II head mounted system using nine point calibration. We recorded each participant's dominant eye movements using the Miles test (Miles, 1930). After adjusting the eye-tracker, participants read the written instructions of the experiment on a computer screen. They sat approximately 45 cm away from the computer screen. Instructions were orally repeated to ensure that every aspect of the experiment was understood. In addition to looking at the correct picture, participants were also asked to choose the correct picture by pressing either the right or the left button on a gamepad. This could only be pressed once the written sentence was fully presented. Hence, we ensured that the participants had seen the whole sentence before answering. They had a one-second span to answer, signaled by a green light. In case they did not answer in time, a warning sign appeared (see Figure 5). This measure was a way for us to control for comprehension but also to give a concrete goal to our participants, which naturally leads them to look more at the picture they want to validate (Hawkins 1999).

Each session lasted less than 30 minutes.

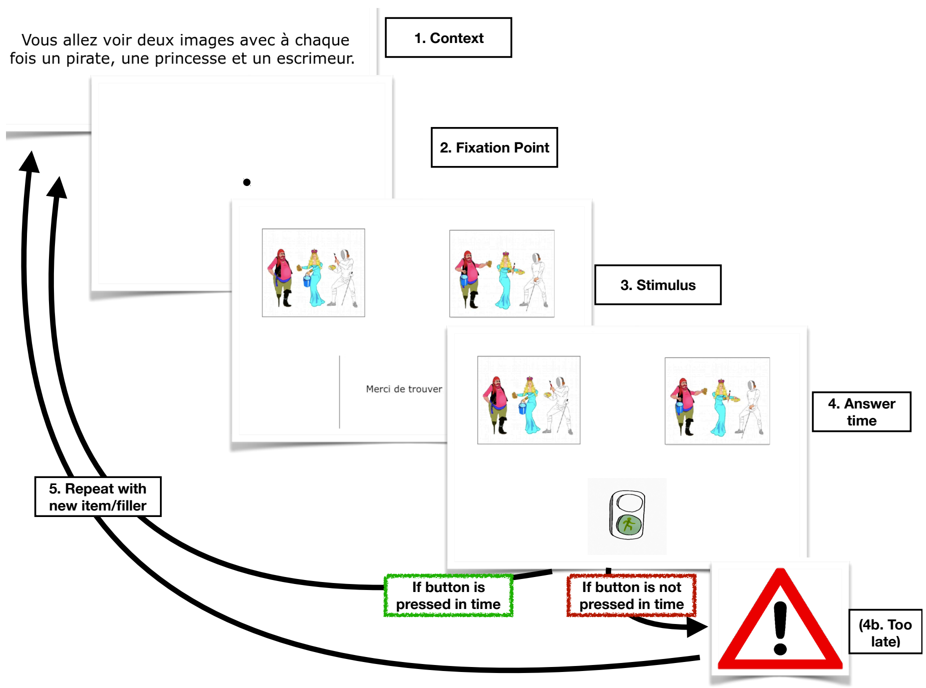

Figure 5: Illustration of the structure of each trial.

2.3. Participants

21 native French speakers participated in the experiment (18 women, mean age: 36 years old, σ =36). One was excluded because s/he was bilingual. They were recruited via the RISC plateform (http://www.risc.cnrs.fr). They had normal or corrected-to-normal vision. Every participant gave their written consent and received 8 euros for their participation. The meta-data have been

anonymized following the CER-PD[5] and the CNIL[6] recommendations.

2.4. Hypotheses

Given that subject relative clauses are syntactically easier to process than object relative clauses in French (Baudiffier et al. 2011, Frauenfelder et al. 1980, Pozniak 2018) looks at the correct picture should start earlier and be more frequent for subject relative clauses than for object relative clauses.

2.5. Results

2.5.1. Answer accuracy

Methods of analysis. We have a ternary dataset since we coded '1' for correct answers, '0' for incorrect answers and '-1' for lack of button pressing. We had planned in advance to exclude participants displaying more than 25 % misses, which did not happen in this group. Since there were only two cases of misses across items and participants, we excluded these cases and only kept accuracy as binary variable with '1' (correct) and '0' (incorrect). Results were analyzed with the R software (version 4.0.0, R Development Core Team, 2005) using generalized linear mixed models using the binomial family via the glmer function (package lme4, Bates et al. 2015). Clause type (subject relative/object relative) was the independent variable coded as 1 for subject relative and 0 for object relative. We applied mean centred coding. Random variables were participants and items. For both random variables, we included random slopes for relative clause type. When necessary, we enforced zero correlations between random effects to avoid overparameterization or false convergence (Bates et al. 2015)[7]. Results are presented in Figure 6.

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[5] Comité d'Éthique pour la Recherche - Paris Descartes

[6] Commission Nationale de l'Informatique et des Libertés.

[7] Detailed analyses are available on the OSF repository (Experiment 1 section `https://osf.io/67efy/?view_only=9b97b23fd5ac4a82b6e82be140e25000`)

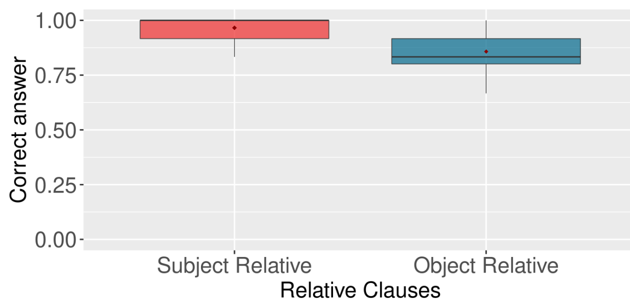

Figure 6: Mean accuracy for subject and object relative clauses

As expected, the results show high levels of accuracy in both conditions, with a mean performance of around 91 percent. Overall the accuracy was better for subject relative clauses with an accuracy of 96% against 86% for object relative clauses. Using the Binomial regression model, we found that this difference was significant (Estimate=1.84, z-value= 3.53 and p-value < 0.001).

Eye-movements.

Methods of analysis. The results were analyzed with R (version 4.0.0). We used the Eyetracking-R package Dink & Ferguson (2015) to clean, analyze and plot our data. We excluded trials presenting more than 25% of Trackloss. The independent variable was relative clause type (subject/object) and time (as continuous variable). The dependent variable was the empirical logit of looks (Barr 2008) to the correct picture versus the incorrect picture and the video stimulus from the beginning of the relative clause (2000 ms) until the end of the sentence (8000 ms). So we used the ratio of looks to the correct picture versus looks to other interest areas (other picture only for the results presented in this paper[8]). We analyzed our data through linear mixed-effects models

[8] The analysis with a different treatment of the response proportions (i.e. looks to the correct picture versus looks to the incorrect picture and the video stimulus) is available on the OSF repository (Experiment 1 section `https://osf.io/67efy/?view_only=9b97b23fd5ac4a82b6e82be140e25000`).

(Barr et al. 2013). The independent variable was coded as 1 (subject relative clause) and 0 (object relative clause) and we applied mean centered coding. The random variables were participants and items. For both random variables, we included random slopes for relative clause type. When necessary, we enforced zero correlations between random effects to avoid overparameterization or false convergence (Bates et al. 2015). All data and analysis code used are available on the OSF repository (Experiment 1 section `https://osf.io/67efy/?view_only=9b97b23fd5ac4a82b6e82be140e25000`).

Figure 7 shows proportion of fixations on the correct picture (versus the incorrect picture) from the head of the relative clause until the end, for subject and object relative clauses.

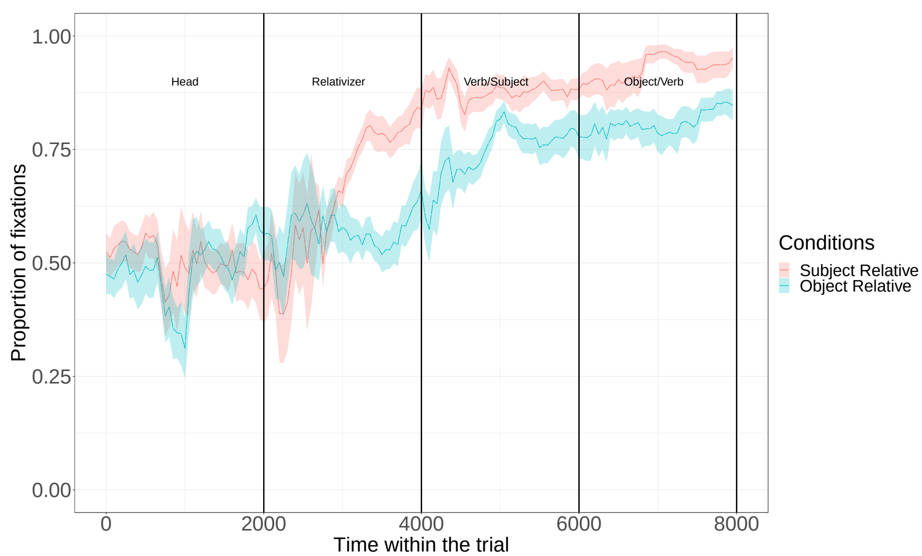

Figure 7: Proportion of correct fixations for subject relative clauses (red) and object relative clauses (blue). *The x-axis represents time and the y-axis represents proportion of fixations on the correct image every 50ms. The black bars help situating each key element of the sentence, the head, the relativizer, the verb or subject of the relative clause and the object or verb. 0 means the onset of the head.*

In Figure 7, we can see that the subject relative clauses are understood correctly earlier and more often than object relative clauses. Linear mixed models showed a significant effect of clause type (Estimate=9.217e-01, t=3.74, p< .001) with proportion of correct fixations higher in subject relative clauses than in object relative clauses. There was also an effect of time (Estimate=2.192e-02, t=52.95, p< .001): participants looked more often at the correct picture across time. No significant interaction between time and clause type was found.

2.6. Discussion

Through our visual-only paradigm, we effectively replicated the results obtained in its audio-visual alternative, in Pozniak (2018). This means that the sensory modality used for stimulus display does not affect the reliability of the experimental design: in both audio-visual and visual-only alternatives, we observe comparable processing mechanisms.
A remark is needed regarding the naturalness of the French sentences used and the way utterances were segmented. An advantage of eye-tracking studies over self-paced reading tasks is that they allow presenting ecological data at a natural pace. This choice of design is however completely deliberate, since it was, to our knowledge, the only way to ensure maximal comparability between the French and LSF displays. As we will see, Deaf signers receive the stimuli visually and sequentially, they cannot look back at what was signed before. As shown in the results, the design we implemented allows a similar sequential and visual display of French.

With all these considerations in mind, the striking result of this study is that we were able to replicate the previous findings on French. We can, therefore, confirm that the syntactic asymmetry between SRC and ORC is very robust in French. Now that we have demonstrated the validity of our visual-only design in an already investigated language, we can adapt it to explore subject and object relative clause processing in LSF.

3. Testing relative clauses asymmetry with Deaf signers

3.1. Design

The design was the same as the French visual-only protocol. We used the same 24 items[9], 25 fillers, and eight practice items/fillers to record the four lists of LSF stimuli. No written French was used at any stage of the experiment itself.

3.2. Material

The only difference lies in the linguistic stimuli displayed which are LSF videos and not written French (see Figure 8).

Figure 8: Experimental display of an item in LSF.

[9]There was a technical problem leading to two items wrongly coded, one supplementary item (25 instead of 24) and not the same number of items per participant. We corrected the coding before analysis and kept the supplementary item.

All the videos were annotated through ELAN[10] in order to obtain the time code corresponding to critical signs. These were, for SRC: the head noun, the relative pronoun PI, the verb of the relative clause, its object and the end of the sentence (cf. Figure 9). For ORC the critical signs were: the head, the relative pronoun, the subject of the RC, its verb and its end as well.

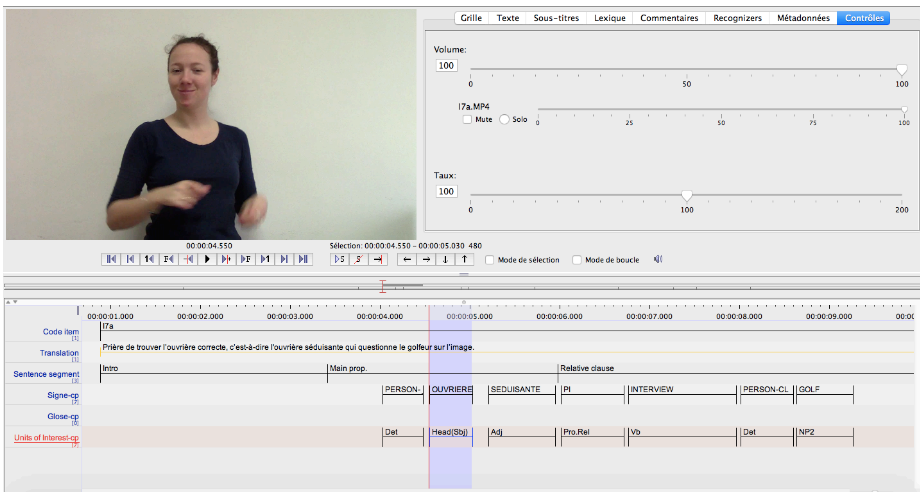

Figure 9: Screen capture of ELAN interface and template used to retrieve time codes of each critical sign.

We only used PI-relative clauses, where "PI" is a relative pronoun, despite LSF displaying alternative strategies. PI-relatives are the only non-equivocally restrictive strategy and the best described one (cf. Hauser 2016, Hauser & Geraci 2017, Hauser 2019).

The mean of the time codes was then used to visually indicate them on the plot. This allowed us to understand at which moment during the sentence was the correct Area of Interest fixated by participants.

Additionally, we asked our LSF consultant, who signed the stimuli, to con-

[10] ELAN (Version 5.8) [Computer software]. (2019). Nijmegen: Max Planck Institute for Psycholinguistics, The Language Archive. Retrieved from https://archive.mpi.nl/tla/elan

sistently use the classifier 'PERSON-CL' before every noun-phrase depicting a human being. While its presence is optional in many professional nouns, it is obligatory in a subset of them (cf. example 9). To avoid undesirable effects linked to its presence/absence, we preferred having it everywhere.

(9)
- * MAYOR
  PERSON-CL MAYOR
  'Mayor (of the town).'
- LABOURER
  PERSON-CL LABOURER
  'Factory worker.'

As for fillers, we used other types of sentences, commonly referred as question/answers in sign language literature, but which are interpreted as declarative sentences (see Hauser 2018). An example of both SRC and ORC items and a filler, are provided in examples (10)-(11).

(10) Items

a PLEASE CHOOSE GOOD PERSON-CL PRINCESS, SO PERSON-CL PRINCESS BEAUTIFUL REL-P PAINT PERSON-CL FENCER SRC
'Please choose the correct princess, meaning the beautiful princess who paints the fencer.'

b PLEASE CHOOSE GOOD PERSON-CL PRINCESS, SO PERSON-CL PRINCESS BEAUTIFUL REL-P PERSON-CL SWORDSMAN PAINT ORC
'Please choose the correct princess, meaning the beautiful princess who the fencer paints.'

(11) Filler

a PLEASE CHOOSE GOOD PICTURE. IX-3 WHAT DOG
'Please choose the correct picture. That is the dog.'

As for the French experiment, we checked the pace of the video-stimuli through a pilot study involving 5 participants (all Deaf). At normal speed[11], our participants were not able to look at the LSF sentences while simultaneously investigating the pictures. We slowed the videos down to 50 % of their original pace and controlled that the resulting videos were correctly understood and appeared natural to our pilot group.

3.3. Procedure

Instructions were provided in LSF on screen and we repeated them in LSF to ensure maximum clarity. The rest of the procedure was the same as in the French experiment.

3.4. Participants

We recorded data from 33 Deaf signers, 18 women and 15 men. There is a considerable age variation among participants, ranging from 19 to 72 years old, with a mean of 39 years old and a standard deviation of 12 y.o. The population of Deaf signers vary greatly regarding their linguistic backgrounds depending on their familial and scholar environment. Therefore, to ensure a better representation of the different linguistic profiles, we collected meta-data regarding the signing background of participants (age of first exposure to LSF, presence or not of Deaf relatives, modality of communication with parents, siblings, other relatives, type of education whether oralist, bimodal or mostly LSF...) through a questionnaire. The meta-data have been anonymized following ethical and security standards provided by the CER-PD and the CNIL.

We thus recruited 15 native/near native (exposed to a sign language before the age of 3 y.o. with a mean age of acquisition of 1.3 y.o., SD = 1.3), and 18 early and late LSF/signers (mean age of acquisition = 9 y.o., SD = 6.3). One participant was excluded due to an age of acquisition exceeding 30 years old.

[11] In fact, our informant signs very fast. Other informants' production might not need to be slowed down that much.

3.5. Hypotheses

If there is an effect of relative clause type, proportion of correct fixations should be higher for subject relative clauses than for object relative clauses.

3.6. Results

3.6.1. Answer accuracy

Methods of analysis. Again, we have a ternary dataset ('1' for correct answers, '0' for incorrect answers and '-1' for lack of button pressing). We excluded participants who provided no answers (i.e., they just did not press any button in time) for more than 25% of the trials (N=3). Two of them were also part of the six participants excluded for displaying less than 70% of accuracy on fillers. Such a low accuracy is interpreted either as a lack of attention, a lack of LSF understanding, or some other factor which surely prevented them from performing correctly. All in all, we present the accuracy measures of 26 participants. We kept accuracy as a binary variable with '1' (correct) and '0' (incorrect). Results were analyzed with the R software (version 4.0.0, R Development Core Team, 2005) using generalized linear mixed models with the binomial family variable via the glmer function (package lme4, Bates et al. 2015). The independent variables were Clause type (subject relative/object relative, coded as 1 for subject relative and 0 for object relative) and age of acquisition as a continuous variable. We applied mean centred coding for these independent variables. Random variables were participants and items. For both random variables, we included random slopes for relative clause type, and we also included by-item slopes for age of acquisition. We enforced zero correlations between random effects to avoid overparameterization or false convergence (Bates et al. 2015)[12]. Results are presented in Table 10.

[12] Detailed analyses are available on the OSF repository (Experiment 2 section `https://osf.io/67efy/?view_only=9b97b23fd5ac4a82b6e82be140e25000`

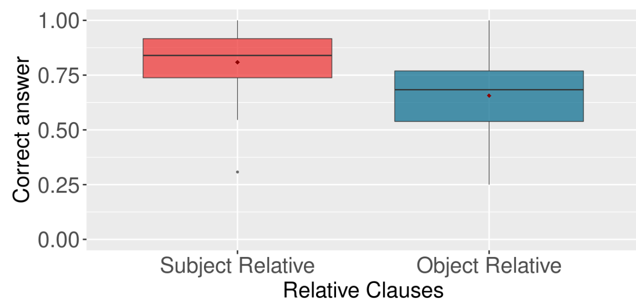

Figure 10: Mean accuracy for subject and object relative clauses

As illustrated in Figure 10, subject relative clauses are accurately understood in 81% of the cases on average, while object relative clauses are accurately understood in 66% of the cases. Using binomial regression models, we found that subject relative clauses are significantly more correctly understood than object relative clauses (Estimate=0.88, SE=0.32, z=2.78, $p<0.01$), comparable to what we observed for French native speakers.

Since our experiment involved both native and non-native LSF signers, we included age of acquisition in our model to see whether this distinction correlates with accuracy (see Figure 11).

Binomial regression models showed a marginal effect of age of acquisition on accuracy (Estimate = -0.06, SE = 0.04, z = -1.7, $p<0.1$). This marginal effect indicates that the age of acquisition may impact relative clause processing. There was no significant interaction between the age of acquisition and clause type.

3.6.2. Visual processing

Method of analysis. We analyzed the results the same way as in the previous experiment. Results were analyzed with R (version 4.0.0). We used the Eyetracking-R package Dink & Ferguson (2015) to clean, analyze and plot our data. We excluded trials presenting more than 25% of Trackloss. Independent variables were relative clause type (subject/object) and time (as continuous

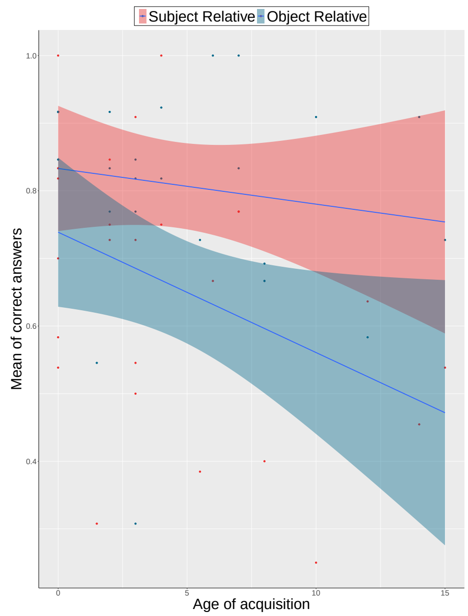

Figure 11: Mean accuracy for LSF participants for relative clauses and age of acquisition of the LSF

variable). The dependent variable was the empirical logit of looks Barr (2008) to the correct picture versus the other (incorrect) picture and the video from the beginning of the relative clause (3240 ms) until the end of the sentence. So we used the ratio of looks to the correct picture versus looks to other interest areas (other picture only for the results presented in this paper[13]). We analyzed our data through linear mixed-effects models (Barr et al. 2013). The independent variable was coded as 1 (subject relative clause) and 0 (object relative clause) and we applied mean centred coding. Random variables were participants and

[13]Like for the French experiment, the analysis with another treatment of the response proportions (i.e. looks to the correct picture versus looks to the incorrect picture and the video stimulus) is available on the OSF repository (Experiment 2 section `https://osf.io/67efy/?view_only=9b97b23fd5ac4a82b6e82be140e25000`).

items. For both random variables, we included random slopes for relative clause type. When necessary, we enforced zero correlations between random effects to avoid overparameterization or false convergence (Bates et al. 2015). All data and analysis code used are available on the OSF repository (Experiment 2 section `https://osf.io/67efy/?view_only=9b97b23fd5ac4a82b6e82be140e25000`).

Figure 12 shows proportion of fixations on the correct picture (versus the incorrect picture) from the head of the relative clause until the end, for subject and object relative clauses.

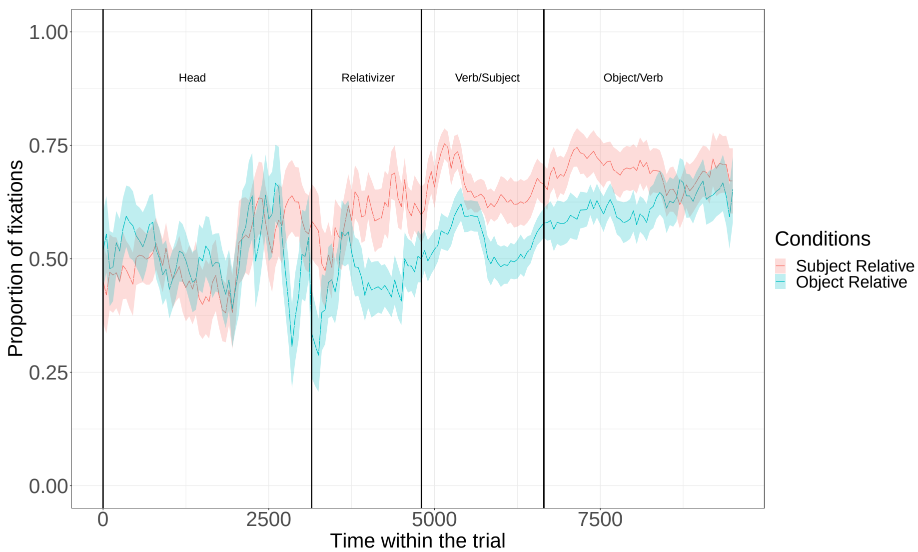

Figure 12: Fixation of correct pictures in subject relatives(red) and object relative(blue) conditions.

The x-axis represents time and the y-axis represents the proportion of fixation on the correct image. The black bars help situating each key element of the sentence, the head, the relativizer, the verb or subject of the relative clause and the object or verb.

Figure 12 shows an asymmetry between subject relative clauses and object relative clauses: subject relative clauses are understood and processed earlier than object relative clauses. Using linear mixed models, we found a significant effect of clause type (Estimate=0.79, t=2.67, $p < .005$) with proportion of correct fixations higher in subject relative clauses than in object relative clauses. We also found an effect of time (Estimate=0.12, t=20.16, $p < .001$): participants looked more often at the correct picture across time. No significant interaction between time and clause type was found.

4. Discussion

Through our visual-only adaptation of Pozniak (2018)'s audio-visual protocol, we have been able to capture in a first experiment the syntactic asymmetry in favor of SRC that she found in French. The effect of condition is visible both through behavioral data (accuracy) and through eye-tracking data with correct pictures being fixated earlier and with more accuracy when participants see a subject relative clauses than when they see an object relative clauses.

Having validated the reliability of our visual-only design, we then ran a second experiment on LSF, aiming at investigating for the first time the processing of relative clauses in a sign language. Through both behavioral and online measures, we have shown that LSF signers process SRC faster and better than ORC. The results indicate that subject relative clauses are syntactically easier to process than object relative clauses in French Sign Language. We can now conclude that the asymmetry between SRC and ORC also extends across modalities. The marginal effect of age of acquisition that we found is in line with previous studies showing that the age of acquisition of sign language can lead to differences in the linguistic competence of adult signers (Friedmann & Novogrodsky 2004, Emmorey et al. 1995).

This finding reasserts the comparability between spoken and signed modalities. When they use the same structural strategies, such as post-nominal externally headed relative clauses, sign languages are subject to the same biases as spoken languages. This in turn confirms that studying sign languages with the tools already developed for spoken languages is a good opportunity to both fasten their linguistic description and, more generally, to enrich our general understanding of human languages. While this motto is already acknowledged in formal linguistics, we demonstrate in our study that it should also extend to psycholinguistic studies. With careful controls and pilots, it is possible to adapt existing protocols into a visual-only display to make it suitable for Deaf studies. In this respect, our study paves the way for future fine-grained psycholinguistic investigations of sign language processing.

TO REMOVE FOR ANONYMIZATION PURPOSE:

Ethics statement

The experiments presented in this paper received the validation from the ethical committee 'CER-PD (Comité d'Éthique pour la Recherche - Paris Descartes) under the reference 2019-18.

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