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## Abstract

Relativization is a robust subordinating type across languages, displaying important typological variability concerning the position of the nominal head that the relative clause modifies, and sign languages are no exception. It has been widely assumed since Keenan & Comrie (1977) that the subject position is more accessible to relativization than object and oblique positions. The main aim of this paper is to investigate the extension of this famous generalization both across modalities (sign as opposed to spoken languages) and across relativization typologies (internally as opposed to externally headed relatives), and to verify how it interacts with age of first language exposure. We here report the results of a sentence-to-picture matching task assessing the comprehension of subject and object relative clauses (RCs) in three sign languages: French Sign Language (LSF), Catalan Sign Language (LSC), and Italian Sign Language (LIS). The results are that object RCs are never easier to comprehend than subject RCs. Remarkably, this is independent from the type of relative clause (internally or externally headed). As for the impact of age of exposure, we found that native signers outperform non-native signers and that a delay in language exposure emphasizes the subject/object asymmetry. Our results introduce a new potential diagnostic for LF movement: the existence of a Subject Advantage in comprehension can be used as a reliable and measurable cue for the existence of long-distance dependencies, including covert ones.

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# 1 Introduction

Relativization is a very robust subordinating type across languages, displaying an important typological variability concerning the position of the nominal head the relative clause modifies (de Vries 2001). Sign languages are no exception, robustly displaying relative clauses and exhibiting the same typological variability that is attested in spoken languages.

It has been widely assumed since Keenan & Comrie's Accessibility Hierarchy (1977) that subject positions are more accessible than object positions in relativization. The main aim of this paper is to investigate the extension of this famous generalization both across modalities and across relativization typologies, and verify how it interacts with age of first language exposure (AoE). We here report the results of a sentence-to-picture matching task assessing the comprehension of subject and object relative clauses (RCs) in three sign languages: French Sign Language, LSF, Catalan Sign Language, LSC, and Italian Sign Language, LIS, reflecting some typological variability.

We have three main research questions. First: as predicted by the Accessibility hierarchy, externally headed relative clauses[1] display a clear subject/object asymmetry in spoken languages. We want to verify whether the same asymmetry holds in sign languages. LSF is especially relevant on this question, since it displays this type of relatives. Second, we want to investigate what happens with the comprehension of internally headed RCs, which have been poorly studied from this point of view, even in spoken languages. LIS and LSC both use internally headed relative clauses and provide data that are directly relevant for this question. Third, we aim at tracing the impact of age of first language exposure on the comprehension of relative clauses by comparing three groups of Deaf signers with different AoE to (sign) language.

Before entering into these questions and describing the way they are addressed in the structure of the paper, let us briefly remind how relatives vary typologically, and how sign languages enter this picture.

# 2 Main relativization strategies

Restrictive relative clauses are clauses modifying a nominal constituent, called the head. Irrespective of language modality, the main typological variation concerns the position of the head with respect to the relative clause modifying it.

*Externally headed relative clauses*, illustrated with the English example in (1) and the Turkish example in (2), display a clear separation between the clause and the nominal head (in bold), which is thus external to the relative clause.

(1) the **cat** [$_{RC}$ that _ kicked the dog]

(2) *Turkish* (Kornfilt 1997: 29)

| | | | | | | |
|---|---|---|---|---|---|---|
| [[$_{RC}$ _ | geçen | yaz | ada-da | ben-i | gör-en ] | **kişi-ler** ] |
| _ | last | summer | island-LOC | I-ACC | see-(SPart) | person-PL |

'the people who saw me on the island last summer'

While they are both externally headed, the relative clause in English (1) is postnominal, while the relative clause in Turkish (2) is prenominal, another important typological difference. In both cases, the relative clause displays a gap corresponding to the position where the head is interpreted. Both (1) and (2) are called *subject relative clauses* because the gap sits in the subject position of the embedded clause.[2]

In *internally headed relative clauses*, on the other hand, the noun modified by the relative clause is internal to the clause itself, which therefore contains no gap. This type of relativization

1 We ignore here the important distinction between restrictive and appositive relative clauses, and only focus on restrictive relatives all along the paper.

2 In some languages, such as Arabic for example (Aoun et al. 2010), externally headed RCs display a resumptive pronoun instead of the gap. This resumptive strategy will not be relevant here.

strategy is illustrated in (3) with a Japanese example. Here the head nominal sits in the object position within the relative clause, and (3) is thus an *object relative clause*.

(3) *Japanese* (adapted from Shimoyama 1999: 147)
[$_{RC}$ Taro-ga sara-no ue-ni **keeki-o** oita-no]-o
[Taro-NOM plate-GEN on-LOC cake-ACC put-NM]-ACC
'the piece of cake which Taro put on a plate'

Finally, RCs may vary as to their position within the main clause. While all the examples discussed so far present relative clauses in isolation, they can of course modify nominals that occupy various functions in the clause. The subject RC in (1) can for example modify a head that serves as the subject (4a) or object (4b) of the main clause.

(4) a. [$_{DP}$ The **cat** that kicked the dog] is black.
b. I punished [$_{DP}$ the **cat** that kicked the dog].

The languages under investigation in this paper, LSF, LIS and LSC, reflect the diversity of relativization strategies briefly outlined here, but in a modality, the signed modality, that also exhibits some important specificities.

## 2.1 Sign languages within linguistic research

Research into sign languages is a young field when compared to spoken language studies. With our study, we also aim at contributing to the understanding of the nature of sign languages with respect to spoken languages.

Over the past decades, an ever-growing body of research has shown that sign languages resort to mechanisms that are sufficiently similar to those observed in spoken languages as to allow cross-modal generalizations in all linguistic domains. At the same time, the visual modality does have an impact on language organization and articulation, and its unique features afforded by the modality should not be downplayed in linguistic descriptions. This is particularly clear when it comes to the grammatical use of the signing space, as reflected by the glossing conventions that have been elaborated specifically to report on sign languages. We here follow the conventions adopted in the SIGN-HUB grammars (*https://sign-hub.eu/grammar*), that we briefly introduce now to facilitate the reader of this paper.

First of all, signs are glossed using non-inflected English words in small capital letters. As for spatial information, it is encoded through the use of indices. When a nominal sign is articulated in a specific location in the signing space, this is signaled with an index letter. When a nominal sign is body anchored, it might still carry an index to indicate possible agreement or coreferential relations the sign might entertain. Pronominal pointing pronouns are referred through the gloss "IX", followed by an indexical number indicating person marking and/or a letter to indicate the specific location in the neutral signing space where they are articulated. Shared indices signal co-referring elements. The same conventions apply to directional verbs (i.e. verbs that display spatial agreement between a starting and an ending location, see Padden 1988) or any sign realized in a specific location in space. Finally, non-manual markers are linguistic forms that do not imply the use of the hand; they can include movement of the body or the eyebrows, eye-gaze direction, and any other facial expression. Non-manual markers and their spreading over manual signs are signaled through a line extending above the signs they co-occur with. These glossing conventions are exemplified in the following French Sign Language (LSF) sentence, in which "bt" refers to body turn, "re" to raised eyebrows and "rg" to right gaze.

(5) *French Sign Language* (Hauser 2019: 170)
__________bt,re ________________rg,re
MARIE$_a$ $_{3a}$SAY$_1$ POSS$_{3a}$ SISTER NICE
'Marie says to me that her sister is nice.'

## 2.2 The structure of this paper

The paper is organized as follows: Section 2 presents an overview of the different questions we are addressing, starting with what is known about biases in processing externally headed RCs, followed by an outline of the puzzle of internally headed RCs (§2.2), and a brief overview of the relevance of age of first language exposure in syntactic competences (§2.3). Section 3 offers a description of how relativization works in the three sign languages under investigation, LSF (§3.1), LIS (§3.2) and LSC (§3.3). Section 4 presents our study on the comprehension of RCs in these three languages and Section 5 details its results, by presenting the analysis of accuracy (§5.1) and that of errors (§5.2). Section 6 provides a general discussion and Section 7 briefly concludes the paper.

## 3 Dimensions of variation: The Accessibility Hierarchy across typology and the effects of first language exposure

A famous finding revealing asymmetries between different types of relatives is Keenan & Comrie's (1977) Accessibility Hierarchy, a scale elaborated on the basis of approximately 50 languages on accessibility to relativization according to the grammatical function of the RC head. It captures the fact that while all 50 languages allow relativization over a subject like in (1), repeated here as (6), fewer languages display object relative clauses like (7), and fewer and fewer languages allow relativization of further positions along the scale (see (8)).

(6) the **cat** [that __ kicked the dog]

(7) the **cat** [that the dog kicked __]

(8)

| Accessibility Hierarchy (Keenan & Comrie, 1977) |
|---|
| Subject > Direct Object > Indirect Obj. > Oblique case, Object of Comparison > Genitive |

As they elaborate this scale, Keenan & Comrie make the hypothesis that this typological implication correlates with processing complexity, hence turning the Accessibility Hierarchy into a "predictor of psychological complexity" (Keenan & Comrie 1977: 61). Subject relative clauses would be easier and faster to process and acquired earlier than object relative clauses, and the same would hold for further positions along the scale. Their hypothesis was first supported by Keenan & Hawkins' (1974/1987) study on language acquisition, through a sentence repetition task, in which the performance of 10-year-old English children statistically correlated with the position of the relative head along the Accessibility Hierarchy.

This phenomenon, referred to as the "Subject Advantage", holds across methods and languages. As for English, subject RCs are produced at an earlier age in acquisition and in higher proportion than object RCs (Diessel 2004). Adults read object RCs significantly slower than subject RCs and obtain lower accuracy scores in comprehension questions (King & Just 1991). A similar Subject Advantage in the form of longer fixations on object RCs compared to subject RCs was also captured in eye-tracking studies (Traxler et al. 2005) and in Electroencephalogram (EEG) studies that associated complexity to a higher electrical signal of the Left Anterior Negativity (LAN) (Müller, King, & Kutas 1997). The Subject Advantage was also confirmed in functional Magnetic Resonance Imagery (fMRI) studies (Constable et al. 2004) and Positron Emission Tomography (PET) studies (Stromswold et al. 1996). These results have been replicated in French (Baudiffier et al. 1990), German (Mecklinger et al. 1995) and many other languages.

As to how to explain such asymmetry, there is no general consensus, with proposals pointing at resource-based effects related to structural distance (Frazier 1987; Hawkins 1999), intervention (Friedmann et al. 2009), linear distance (e.g. King & Just 1991; Gibson 2000) or, canonical order effects (Diessel & Tomasello 2005), distribution-based effects (e.g. Mak et al. 2006), and prominence-factors (van Valin & Wilkins 1996). These different accounts make different predictions about the cross-linguistic extension of the Subject Advantage. While they all predict a Subject Advantage in SVO languages with postnominal relatives, like English, they differ in their predictions concerning other word orders and other relativization strategies.

The structural distance hypothesis (Hawkins 1999) predicts the asymmetry to hold across word orders and relativization strategies, at least as far as externally headed relative clauses are concerned. As for postnominal RCs, as in English, the idea is that the complexity captured by the Accessibility Hierarchy derives from the fact that speakers need to keep the head of the RC in their memory until they encounter the gap position. Since an object gap, as in (7), is structurally further away from the head than a subject gap like (6), an object RC is harder to process than a subject RC. The same asymmetry is predicted to arise with prenominal RCs, where the speaker needs to wait to find the head of the RC once they encounter a gap. Structurally (but not linearly), the gap of an object RC (as 10 in Turkish) is more deeply embedded than that of a subject RC (cf. 2 repeated as 9 below).

(9) *Subject relative clause in Turkish* (Kornfilt, 1997: 29)

| | | | | | | |
|---|---|---|---|---|---|---|
| [[$_{\text{RC}}$ _ | geçen | yaz | ada-da | [$_{\text{VP}}$ ben-i | gör-en]] | **kişi-ler** ] |
| _ | last | summer | island-LOC | I-ACC | see-(SPART) | person-PL |

‘the people who saw me on the island last summer’

(10) *Object relative clause in Turkish* (Kornfilt, 1997: 29)

| | | | | | | |
|---|---|---|---|---|---|---|
| [[$_{\text{RC}}$ pro | geçen | yaz | ada-da | [$_{\text{VP}}$ _ | gör-düg-üm ]] | **kişi-ler** ] |
| pro | last | summer | island-LOC | _ | see-OPART-1.SG | person-PL |

‘the people who(m) I saw on the island last summer’

The same prediction of a universal subject advantage holds for other structural hypotheses, such as Relativized Minimality and Intervention (Friedman et al. 2009), given that by definition a subject will invariably intervene structurally between an object gap and its antecedent, no matter their respective linear positions.

Other accounts that are based on linear factors predict the Subject Advantage to hold only with some word orders and some types of relativization strategies. In particular, accounts based on linear distance predict that languages with prenominal relative clauses should exhibit an object advantage. To go back to the Turkish examples above, the subject gap is linearly further away from the head in (9) than the object gap in (10). If what counts is linear distance, an object advantage is predicted to hold.

Most studies[3] point towards a universal Subject Advantage, holding both with postnominal and with prenominal RCs (see results on Korean by Kwon Nayoung et al. 2013; Kwon Nayoung et al. 2010; O’Grady, Lee, & Choo 2003; Slobin & Zimmer 1986; but also on Japanese by Miyamoto & Nakamura 2013; Turkish by Özge, Marinis, & Zeyrek 2009; on Cantonese by Huang Jiaying & Donati 2019; on Wenzhounese by Hu Shenai, Cecchetto & Guasti 2018; on Mandarin Chinese by Lin Chien-Jer & Bever 2006; Wu Fuyun et al. 2009; Lau Elaine 2016 and Jäger et al. 2015 a.o.).

Across studies, the Subject Advantage has been shown to be affected and modulated by a number of factors (Vasishth & Lewis 2006). Traxler et al. (2005) and Mak et al. (2006) show that inanimate heads in object RCs drastically reduce the Subject Advantage in English. Similarly, Friedmann & Novogrodsky (2004) show that children easily understand object RCs if the relative clause has a pronominal subject, as in example (10).

(10) I prefer the **princess** [$_{\text{RC}}$ that you are drawing ___ ].

Other factors, such as saliency (Roland et al. 2012; Hale 2016), appear to also have an impact. For this reason, when conducting cross-linguistic studies, it is important to use comparable experimental settings in order to control for the factors that are manipulated. In the experiments that we report about in this article, we will only focus on the syntactic position of the head (subject vs object), and will keep other parameters constant.

Another important factor of variation that might affect the comprehension of a RC concerns its position within the main clause. To clarify, the RC in (10) modifies an object NP, while the same RC in (11) modifies a subject NP.

(11) The **princess** [$_{\text{RC}}$ that you draw ___ ] is strong and powerful.

3 See Gibson (2000), Qiao, Shen, & Forster (2012) or Chen & Shirai (2015) a.o. for data suggesting the existence of an object advantage in prenominal RCs.

In order to avoid any possible effect of this variable, all the RCs in our experiments modify an object NP.

The vast literature on asymmetries in the comprehension, processing, production and acquisition of relative clauses has at least two limitations. One concerns the type of languages investigated, which does not include the sign modality (or barely so). The other concerns the relativization strategy, which is mostly that of (prenominal or postnominal) externally headed relative clauses. One aim of this paper is to contribute to filling these two gaps. As we shall see, LSF displays externally headed RCs, while LIS and LSC both make use of internally headed RCs. If the Accessibility Hierarchy based on the study of spoken languages is valid across modalities, the predictions are straightforward for LSF: since it presents externally headed RCs, we should find a clear Subject Advantage in relative clause comprehension. For LIS and LSC, on the other hand, the predictions are less clear since, to this date, there is close to no research carried out on the Accessibility Hierarchy with internally headed RCs.

## 3.1 The puzzle of internally headed relative clauses

Internally headed RCs are clauses involving no gap, which are however nominal in nature (Cole 1987; Kayne 1994; Keenan & Comrie 1977; or Lehmann 1986). They can even show nominal inflection, as in Japanese, where a case marker (accusative) is attached to the internally headed relative clause in (12).

(12) *Japanese* (Shimoyama, 1999: 147)

| | | | | | | |
|---|---|---|---|---|---|---|
| Yoko-wa | [$_{RC}$ Taro-ga | sara-no | ue-ni | **keeki**-o | oita-no]-o | tabeta. |
| Yoko-Top | [ Taro-NOM | plate-GEN | on-LOC | cake-ACC | put-NM]-ACC | ate |

'Yoko ate the piece of cake which Taro put on a plate.'

Internally headed RCs are analyzed by Kayne (1994), Cole (1987) and Culy (1991), among many others, as the mirror image of externally headed RCs: just like them, they modify a head noun (*keeki*, 'cake in 12) that is shared semantically and syntactically between the main and the relative clause. The only difference between the two constructions from a structural perspective is the overt position of the head, which is either external or internal. For proponents of raising theories, like Cecchetto & Donati (2015), De Vries (2001) or Bianchi (2000), internally headed RCs involve the *covert* movement of the relative head while externally headed RCs involve the *overt* movement of the relative head. For proponents of head-matching theories, like Sauerland (2003) or, more recently, Cinque (2019), internally headed RCs and externally headed RCs are both base-generated with two head nouns, one internal and one external, with one of them deleted at PF.

In both families of analyses, there is no gap within internally headed RCs at least in overt syntax. If the Subject Advantage attested for externally headed RCs is due to the structural distance between the head noun *and the gap* (possibly because the identification of a null category is a complicated business), we would predict internally headed RCs to display no difference in comprehension between subject RCs and object RCs. However, both families of analyses posit that internally headed RCs involve an abstract dependency between two positions. Is comprehension affected by the abstract dependency involved in internally headed RCs in the same way it is affected by the concrete dependency involved in externally headed RCs? If it is, we would predict a Subject Advantage in internally headed RCs as in externally headed RCs.

To this date, very little research has been conducted with these questions in mind, and all come from the domain of L1 and L2 acquisition studies. Jeon Seon & Hae-Young Kim (2007) analyzed the elicited production of 40 L2 learners of Korean, a language displaying both internally headed RCs and externally headed RCs. The aim was to verify whether there is an asymmetry in the acquisition of Subject RCs and Object RCs in head-internal and head-external constructions. What they found was a clear Subject Advantage for externally headed RCs, with L2 learners producing Subject RCs more frequently and more accurately (91.1% of correct answer) than Object RCs (83.7%), but a less clear pattern for internally headed RCs. The authors do not report the accuracy scores, but note that Object RCs are slightly more frequent (6%) than Subject RCs (4. 8%). Similarly, Hu Shenai, Cecchetto & Guasti (2018) made an elicited production study of RCs in Wenzhounese, a language that allows both internally headed RCs and externally headed RCs, and report a Subject Advantage in externally headed RCs, but an object preference in internally headed RCs.

The order of acquisition of internally headed RCs and externally headed RCs itself seems to be different, as shown by a longitudinal study on three Korean children's L1 acquisition conducted by Kim Youn-Joo (1987), who found that Korean children start to produce headless relative clauses around 2 y.o., before producing internally headed RCs, and that externally headed RCs come last. This pattern is also found by Lee Awen Ock's (1991) investigation of the spontaneous production of 36 Korean children, with a mean age of acquisition of internally headed RCs around 27 months, and around 36 months for externally headed RCs. The same pattern is confirmed by Jeon Seon & Hae-Young Kim (2007) for L2 learners of Korean.

These scattered results, although interesting, are not sufficient to draw any conclusions regarding the Accessibility Hierarchy and its predictive power when it comes to internally headed RCs. It is however interesting to note that there seems to be a difference across RC types, and some studies suggest that no Subject advantage or even an opposite Object advantage might hold for internally headed RCs. In the narrow light of these studies, the predictions regarding the Accessibility Hierarchy and the Subject Advantage (if any) when it comes to internally headed RCs are rather blurred. If difficulty arises from structural distance or intervention, there are two possibilities: if what matters is the structural distance between the head noun and the edge of the relative clause where a silent copy is interpreted, we expect to observe a Subject Advantage in internally headed RCs similar to what is observed in externally headed RCs. If on the other hand what matters is that in internally headed RCs there is no gap to fill, we should expect no asymmetry between object RCs and subject RCs.

Additionally, if internally headed RCs are really easier to understand than externally headed RCs, as the studies reported above appear to suggest, this might make the detection of a Subject Advantage more difficult with the former, with participants being too accurate to observe any difference. Yet, on the other hand, the head noun is not easy to identify in internally headed RCs, since it is not singled out by its position. This might involve an extra burden that is not required in the processing of externally headed RCs.

Our study is likely to be able to provide some answers to these questions since both LSC and LIS exploit internally headed RCs. Besides, as we shall see below, Deaf signers include very heterogeneous populations, where differences in AoE might make visible even small processing biases.

### 3.2 Age of first exposure to a sign language

For the vast majority of hearing infants, language exposure starts already within the womb (see DeCasper & Spence 1986, or Gervain et al. 2008 on that matter) and language deprivation is restricted to exceptional cases of severe child abuse. But for the vast majority of deaf infants born in a hearing family, a delay in language exposure occurs, which is due to an incompatibility between the perceptual abilities of the child and the surrounding language. Even with early intervention through hearing aids or cochlear implants, language access is delayed if not provided from birth in a fully accessible way, which is the visual modality (see Hall et al. 2019 or Humphries et al. 2016 a.o.).

As a result, Deaf[4] signing communities are very heterogeneous: few individuals have signing parents/relatives and are exposed to a sign language from birth (i.e. they are native signers in the narrow sense), whereas the vast majority, having non-signing parents, are exposed only to a spoken language in their early life and discover sign language later. This group is composed of people with quite different linguistic profiles, since outcomes of exposure to spoken language through hearing aids only are very variable across individuals, and late exposure to a sign language does not ensure full language acquisition (see Humphries et al. 2016).

The long-lasting effects of this delayed acquisition in adulthood have been discussed in a number of studies focusing mainly on American Sign Language (ASL) and British Sign Language (BSL). In 1993, Mayberry reported that native signers are better at recalling complex ASL sentences than late learners and that, more broadly, the age of ASL exposure is correlated to task performance. This result was confirmed in Boudreault & Mayberry's (2006) experiment,

4 We follow here the standard practice of capitalizing *Deaf* when we refer to individuals who are deaf and identify culturally as belonging to a community, while we keep the simple *deaf* when referring to their auditory condition.

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and in its BSL version (Cormier et al. 2012), where participants had a limited time to determine the grammaticality of a set of sentences they were presented with. Stimuli ranged from simple declarative sentences to more complex ones like interrogatives or relative clauses, and participants' performance decreased as their age of exposure to a sign language increased. At the morpho-syntactic level, Emmorey et al. (1995) highlight the difference in perceiving agreement errors in ASL sentences when comparing native and non-native signers. These results also extend to the morpho-phonological level, with native signers being quicker and more accurate in distinguishing between words and pseudo-words (Emmorey & Corina 1990). It is thus at all levels of the linguistic signal that effects of a delayed sign language exposure can be traced.

These effects have been mainly found in ASL and BSL signers even though their home countries are considered as very advanced in the recognition and diffusion of sign languages: the United States even host the only fully-ASL accessible university, and the United Kingdom is a pioneer in the development and use of sign language in linguistic assessment (see Haug 2005 for a review). This narrow focus makes it all the more important to investigate adult linguistic performance in European sign languages, where deeply rooted public policies favoring oralist education[5] have largely impeded the recognition of sign languages and their importance in individuals' cognitive and linguistic development. It is thus essential to investigate the consequences of a delayed exposure to sign language to better inform policy makers and support Deaf people's efforts in this direction.

## 4 Relative clauses in sign languages

The past 50 years have been rich in research documenting sign language relativization strategies. To date, studies have been carried out on ASL (Liddell 1978, Liddell 1980, Fontana 1990; Miller 1990; Galloway 2011); LIS (Cecchetto et al. 2006, Branchini & Donati 2009, Branchini 2014), Brazilian Sign Language (Libras, Nunes & de Quadros 2005), German SL (DGS, Pfau & Steinbach 2005, Happ & Vorköper 2006), Japanese SL (JSL, Penner et al. 2019), Hong Kong SL (HKSL, Tang Gladys & Prudence Lau 2012; Li 2013), Turkish SL (TİD, Kubus 2011); LSC (Mosella Sanz 2012), and LSF (Hauser 2016; 2019; Hauser & Geraci 2017). These studies demonstrate that sign languages display as much typological variation as found in spoken languages, with some displaying internally headed RCs (ASL, LIS or LSC a.o.), others pre-nominal externally headed RCs (JSL), and some others displaying post-nominal externally headed RCs (LSF, ASL, DGS).

In the vast majority of sign languages, relative clauses are signaled through the use of specific manual and/or non-manual markers, the only exception being JSL, where according to Penner et al. (2019) there is no marking whatsoever signaling relativization. For example, ASL RCs are signaled through backward head tilt, raised eyebrows, and tensed upper lip (Wilbur, 2017). A manual sign dedicated to relativization can also be used. Its nature varies across languages, from relative pronouns (13), to complementizers (14) or nominalizers (15). The relevant manual signs are underlined in the following examples.

(13) *LSF* (adapted from Hauser & Geraci, 2017: 20)

rel
IX$_1$ PREFER **DOG$_I$** [$_{RC}$ PI$_I$ MAN PET ___]
'I prefer the dog that the man pets.'

(14) *ASL* (adapted from Liddell, 1978: 85)

rel
$_1$ASK$_3$ GIVE$_1$ **DOG** [$_{RC}$ URSULA KICK THAT$_C$]
'I asked him to give me the dog that Ursula kicked.'

5 Starting from the International Congress for the Education of the Deaf (ICED) held in Milan in 1880 most Western and European countries based deaf education on so-called "oralism", that is exclusive focus on oral language training by using lip reading and mimicking mouth shapes and breathing patterns of speech. Many European countries have made important steps towards a more inclusive education using sign language, but the oralist tradition is still alive in most language policies towards the deaf (see Lane 1979).

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(15) *LSC* (adapted from Mosella Sanz, 2012)

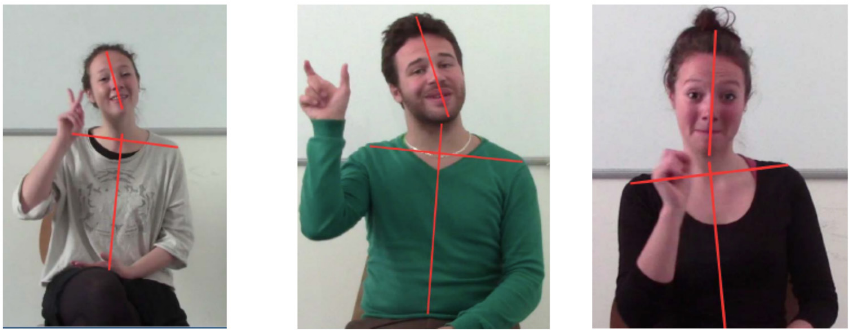
rel
[$_{\text{RC}}$ YESTERDAY **MAN** COME SAME] POSS$_1$ FRIEND
'The man who came yesterday is my friend.'

Regarding comprehension of RCs in sign languages, however, there is close to no research on the topic. Very recently, Hauser & Pozniak (2019) showed that LSF presents a clear Subject Advantage, using an eye-tracking visual world preference paradigm design. Being the first study of this kind, however, its results need to be replicated and expanded, especially with respect to effects of age of first language exposure on participants' accuracy.

In order to start filling in this gap, we chose to analyze the comprehension of relative clauses in LSF, LIS and LSC, three European sign languages that are typologically diverse. Here we briefly report the main features of relativization in the three languages, as they have been described in the literature.

## 4.1 Relative clauses in French Sign Language

LSF allows both SVO and SOV word orders with preference for one or the other varying across individuals (Hauser 2019). It mostly presents externally headed RCs which can be marked in three different ways: through non-manual markers only, with the relative pronoun PI or with the classifier PERSON-CL when the relative clause head is a human entity (Hauser & Geraci 2017; Hauser 2019). All three strategies come with a specific set of non-manual markers which can optionally spread over the head noun as well, glossed as "rel": raised eyebrows, body and head turned towards the locus of the relative pronoun or the head noun with which it agrees in space (see *Figure 1*).



**a.** Non-manual markers on the head noun (VET). **b.** Non-manual markers on the relative pronoun PERSON-CL. **c.** Non-manual markers on the relative pronoun PI.

**Figure 1** Relativization markers in LSF, from Hauser (2019).

In the present study, we focused on the PI-strategy as it is the only strategy that receives an unambiguous restrictive interpretation with any type of head, whether human or not. The sign PI is glossed after its mouthing component since signers co-articulate the syllable [pi] when signing it. It starts with a hand configuration similar to a rounded pinch (F-shape but with non-selected fingers bent) and ends as a pointing sign (similar to the French gesture called "pichenette") agreeing in space with the head noun. An example of subject and object relative clauses in LSF is given in (16) and (17).

(16) *Subject relative clause, LSF* (Hauser 2019: 58)

rel
IX$_1$ PREFER **MAN$_i$** [$_{\text{RC}}$ PI$_i$ __ PET DOG]
'I prefer the man who pets the dog.'

(17) *Object relative clause, LSF* (Hauser 2019: 59)

rel
IX$_1$ PREFER **DOG$_i$** [$_{\text{RC}}$ PI$_i$ MAN PET __ ]
'I prefer the dog which the man pets.'

To avoid variation, all the stimuli we built for our study follow the structure described in the literature, with an SVO order and the relative clause in its base position (Hauser 2019). An example from our dataset is provided for subject relative clauses (see 18 and *Figure 2*) and for object relative clauses (19 and *Figure 3*).

(18) *Subject relative clause, LSF*

rel
HAVE-TO CHOOSE **GIRAFFE**$_i$ [$_{RC}$ PI$_i$ __ $_i$LICK$_j$ COW$_j$ ]
'(You) have to choose the giraffe that licks the cow.'

**Figure 2** Screen captures of the sentence in (18), a subject relative in LSF.

(19) *Object relative clause, LSF*

rel
HAVE-TO CHOOSE **GIRAFFE**$_i$ [$_{RC}$ PI$_i$ COW$_j$ $_j$LICK$_i$ __ ]
'(You) have to choose the giraffe that the cow licks.'

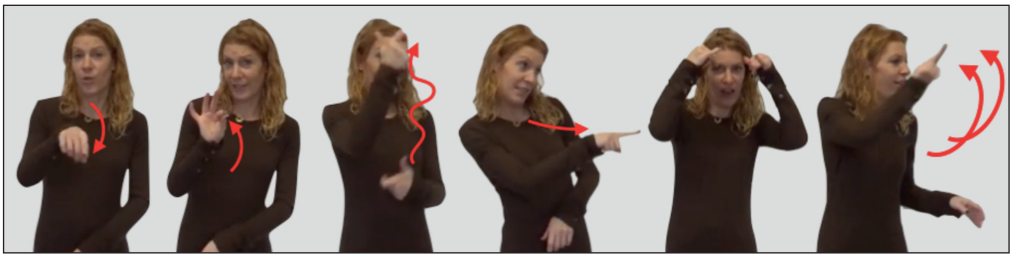


**Figure 3** Screen captures of the sentence in (19), an object relative in LSF.

## 4.2 Relative clauses in Italian Sign Language

LIS is an SOV language. Its most common relativization strategy is to use a fronted internally headed RC[6] marked on its right edge by the relative determiner PE (*Figure 4*). The relative marker PE agrees in location with the head noun. The whole relative clause is marked by a set of non-manual markers glossed as "rel" described as "raised eyebrows, a specific tension of the eyes and upper cheeks, and a forward head nod co-occurring with the sign PE" (Branchini 2014: 189).

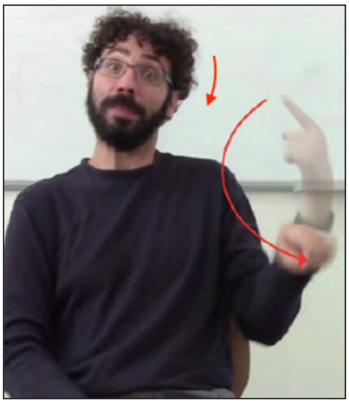


**Figure 4** The sign PE in LIS, from Hauser (2019).

6 See Cecchetto, Geraci & Zucchi (2006) for an alternative analysis in terms of correlative construction.

An example of a subject (20) and an object (21) RC in LIS is provided below.

(20) *Subject relative clause, LIS* (Branchini 2014: 191)

rel

[$_{RC}$ **DOG**$_i$ IX$_{3i}$ EAT A-LOT PE$_i$] DOCTOR VET BRING
'I took the dog that eats a lot to the vet.'

(21) *Object relative clause, LIS* (Branchini 2014: 192)

rel

[$_{RC}$ YESTERDAY **DOG**$_i$ FIND PE$_i$ ] PAOLO$_k$ IX$_k$ WASH
'Paolo washed the dog that I found yesterday.'

For the present study, in order to avoid variation across stimuli, we generalized the use of a classifier handshape (CL)[7] that directly follows the object within the RC (see Benedicto & Brentari 2004, for a description of a similar phenomenon in ASL), as this was strongly preferred by most of our LIS informants. Example (22) and ***Figure 5*** illustrate a subject RC and sentence (24) along with ***Figure 6*** present an object RC using this classifier, both examples are taken from our data set.

(22) *Subject relative clause, LIS*

rel

[$_{RC}$ **GIRAFFE**$_k$ COW$_j$ CL$_j$ $_k$LICK$_j$ PE$_k$] CLICK
'Click on the giraffe that licks the cow.'

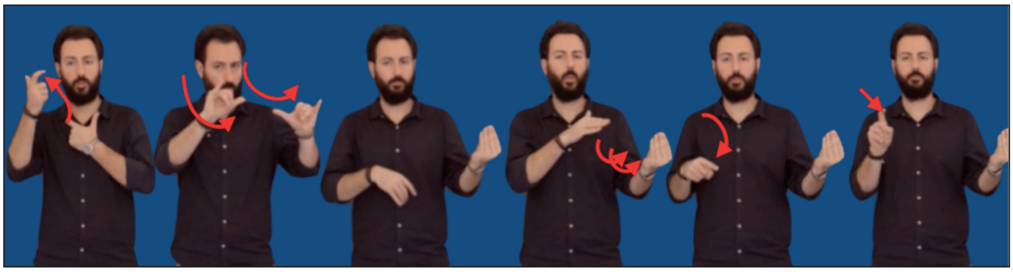


**Figure 5** Screen captures of the sentence in (22), a subject relative clause in LIS.

(23) *Object relative clause, LIS*

rel

[$_{RC}$ **GIRAFFE**$_k$ CL$_k$ COW$_j$ $_j$LICK$_k$ PE$_k$] CLICK
'Click on the giraffe that the cow licks.'

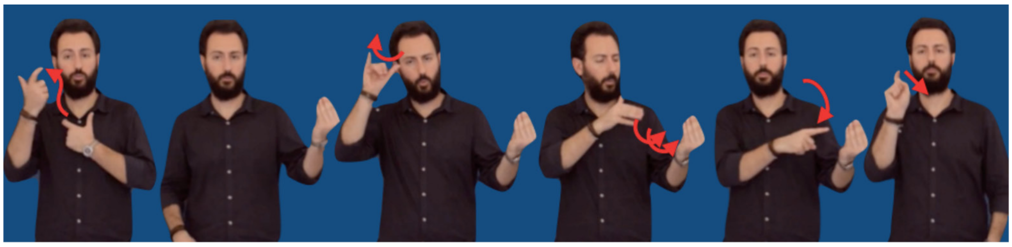


**Figure 6** Screen captures of the sentence (23) in LIS, an object relative clause.

### 4.3 Relative clauses in Catalan Sign Language

Catalan Sign Language (LSC) is also an SOV language having fronted internally headed RCs as the most common strategy for relativization. Here, relatives are signaled either through the use of non-manual markers only, or through the use of a sign glossed as MATEIX[8] in the literature, meaning 'same'. This sign is realized on the shoulder with an arc movement (***Figure 7***). Despite this sign being body-anchored and hence not displaying any agreement, Mosella Sanz (2012)

7 Classifier are signs that can refer to a given class of entities (like vehicles, persons …) and which are used to give spatial, shape and/or motion descriptions. Classifier handshapes are drawn from a closed set and differ from one sign language to another. For a full description see Quer et al. (2017).

8 From this point, this sign will be glossed as SAME.

notes that the head noun is signaled through body leaning (i.e. the signer leans in the direction of the head locus). The whole relative clause is marked through raised eyebrows, squinted eyes and slightly raised shoulders (Mosella Sanz 2012).

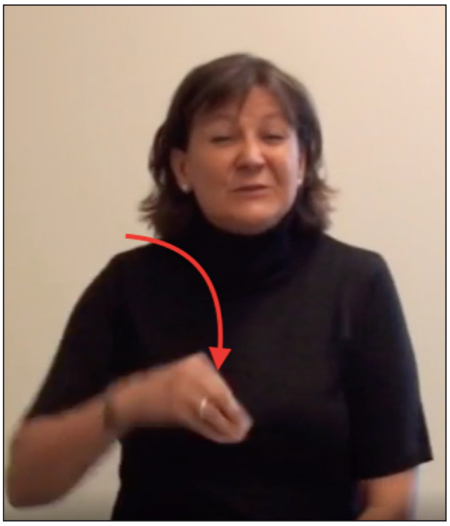


**Figure 7** The sign MATEIX/SAME in LSC, from Barberá (2020).

According to the author, SAME can appear either at the left (see 25, in an object relative clause) periphery of the relative clause or at the right periphery of the relative clause (as in 24, a subject relative clause) without affecting the meaning.

(24) *Subject relative clause, LSC* (adapted from Mosella Sanz 2012: 186)

rel
[$_{RC}$ NOW **GIRL** IX$_3$ AREA CITY LIVE IX$_{LOC}$ SAME] YESTERDAY ONION $_3$GIFT$_1$
'Yesterday we gave onions to the girl who now lives in the city.'

(25) *Object relative clauses, LSC* (adapted from Mosella Sanz 2012: 186)

rel
[$_{RC}$ SAME **MUSHROOM** COLLECT] BASKET CL-PUT-IN-BASKET
'I will put the mushrooms I found in the basket.'

The strategy with the relative marker on the left was preferred by our informants, therefore we adopted it consistently across stimuli. We also minimized variation by always fronting the relative clause before the main clause. An example from our dataset is provided for subject relative clauses (see 26 and ***Figure 8***) and for object relative clauses (27 and ***Figure 9***).

(26) *Subject relative clause, LSC*

rel
[$_{RC}$ SAME **GIRAFFE**$_i$ $_i$LICK$_k$ COW$_k$] IX$_2$ CLICK
'Click on the giraffe that is licking the cow.'

**Figure 8** Screen captures of the sentence in (26), a subject relative clause in LSC.

*Glossa: a journal of general linguistics*
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(27) *Object relative clause, LSC*

rel

[$_{RC}$ SAME **GIRAFFE**$_i$ COW$_k$ $_k$LICK$_i$] IX$_2$ CLICK
'Click on the giraffe that the cow licks.'

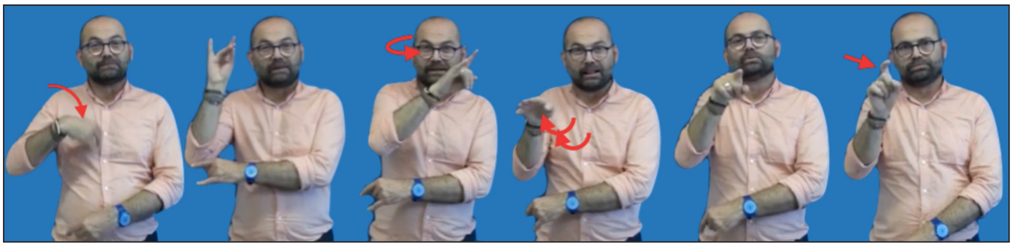

**Figure 9** Screen captures of the sentence in (27), an object relative clause in LSC.

## 5 The present study

This section presents our experiments[9] on RCs comprehension. Remember we had three main goals. The first goal was to investigate whether the Subject Advantage extends across modalities. The LSF experiment is directly relevant for this goal, since LSF displays externally headed postnominal RCs, which invariably exhibit the strongest Subject Advantage in the spoken modality. We thus expect to find a clear Subject Advantage in RC comprehension in this language.

The second goal was to investigate what happens with the comprehension of internally headed RCs, which have been poorly studied from this point of view. LIS and LSC both exhibit internally headed RCs and can provide data that are directly relevant for this question. There are few studies on this topic and they are partially contradictory, therefore it is difficult to have clear expectations. Even looking at theories that have been proposed to explain a Subject Advantage does not offer an unambiguous base to make a prediction.

No Subject Advantage is expected in internally headed RCs if the crucial factor that determines the Subject Advantage is ultimately related to the presence of a gap, say because the subject gap is easier to retain in the memory buffer, being closer to the relative clause head (either linearly or structurally). However, several researchers have proposed that internally headed RCs are only superficially different from externally headed RCs, since the same long-distance movement operation is involved in both, the only difference being that in externally headed RCs the movement is visible while in internally headed RC it applies at LF. If this analysis is correct, and if distance impacts syntactic movement even when the latter takes place at LF, a Subject Advantage might arise in internally headed RCs as well.

To further muddle the picture, internally headed RCs involve another factor of complexity, independent from the subject RC vs object RC contrast, namely the fact that the head is not explicitly marked by occupying a specific position. We expect this factor to impact our results and to reinforce any other bias that we might observe.

The third goal concerns the investigation of the impact of age of first exposure (AoE) on the comprehension of RCs. We expect native signers to outperform early and late signers, and that more complex sentences should be particularly challenging for non-native signers in general and late signers in particular. This means we expect the Subject Advantage to be stronger in non-natives in LSF, and whatever bias we observe with internally headed RCs to be stronger in non-natives in LIS and LSC.

### 5.1 Design and procedure

For each sign language, we developed a sentence-to-picture matching task based on Friedmann & Novogrodsky (2004). In each picture, three characters are displayed: two of them are identical and are either performing an action or undergoing that action with respect to a third different character standing between them (*Figure 10*).

9 All the video items used in the experiments and the scripts for the analyses can be found in the following OSF repository: *https://osf.io/5bdu2/?view_only=683792bb06d2410facb49037a02a85b5*. Images can be consulted by contacting the corresponding author.

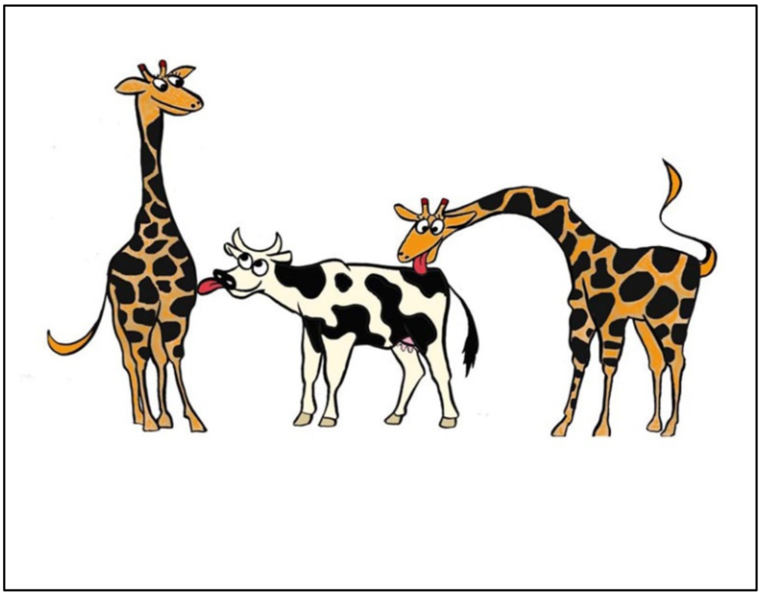

**Figure 10** Three characters, one giraffe licks the cow, and the other one is licked by the cow.

Participants are asked to choose one of the characters based on a sentence containing a relative clause. The head of the relative clause invariably corresponds to one of the matching characters (the giraffes in *Figure 10*), and the RC is either a subject RC (i.e. 'Choose the giraffe that licks the cow') or an object RC (i.e. 'Choose the giraffe that the cow licks'). Some of the pictures were used as fillers, hence associated with a simpler request not including any relative clause (i.e. 'Choose the black and white animal'). The function of the fillers was three-fold. 1) As fillers were simple, participants did not need to keep the same level of concentration throughout the whole experiment and could rest. 2) Performance in fillers was used as a baseline measure of attention and overall comprehension. Participants who were lower than 75% correct in the fillers were excluded. 3) Fillers provided some trials targeting the middle character. Since the experimental design tends to bias participants to always click on the left or right characters, half of the fillers were targeting the middle character while the other half were targeting side characters.[10]

The protocol had a within-participant design, such that the experiment contained two blocks, administered to each participant in two separate sessions or even on separate days, which were the mirror image of each other: if a picture was presented with a subject RC stimulus in the first block, it was then presented with an object RC stimulus in the second block, so that the same picture was never displayed within the same block. Within a single block, half of the items were subject RCs and the other half were object RCs. The same fillers were used across the two blocks. Items and fillers were fully randomized. All the sentences used in the experiments have been elicited with native informants of the investigated sign language. Non-manual markers typical of relativization strategies in each language (see Section 3) are not indicated in the gloss.

The test always started by a video presenting the instructions in the relevant sign language, followed by a short training phase. At the end of the training phase, participants could ask clarification questions. There were minor variations in the general design and procedures across sign languages that we detail now.

### 5.1.1 LSF

For the LSF experiment, each block contained 42 trials (14 subject RCs, 14 object RCs, 14 fillers) preceded by 3 training trials – one subject RC, one object RC and one filler. The full list of items is given in the Appendix. The duration of each testing session was around 20-25 minutes and was embedded within a larger testing session (~ 1h30) during which the participants performed other lexical and syntactic tests.

10 The experiment in LSC presented some minor differences concerning fillers. We detail them in Section 4.1.3.

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Participants were left alone in the experiment room to perform the test on their own. They were sitting approximately 45 cm away from the screen (4:3 display, 22” screen) and answered using a mouse by clicking on the selected character.

For each trial, participants saw first the stimulus video, automatically followed by the picture on which to click to provide their answer (see ***Figure 11***). The stimulus video always started by a small context introducing the characters present in the video (see 28), followed by a request embedding a subject RC (28a), or an object RC (28b) or, if it was a filler, a simpler sentence (28c). Notice that the context did not give any indication regarding the spatial disposition of the various characters, while the request embedding the RC displayed spatial location associated to the arguments of the clause. This spatial information did not always match the spatial arrangement of the characters in the picture (meaning that the left character on the picture was not always signed on the left side of the signer) since we did not want participants to be biased in their answers by this parameter. To avoid participants interpreting spatial information topographically nonetheless, the picture was only made visible after the end of the recorded sentence.

(28) *Context, LSF*
HERE THREE CHARACTER. TWO GIRAFFE ONE COW…
‘There are three characters, two giraffes and a cow.’

a. *Subject relative clause*
… HAVE-TO CHOOSE **GIRAFFE**$_i$ [$_{RC}$ PI$_i$ — $_i$LICK$_k$ COW$_k$].
‘(You) have to choose the giraffe that licks the cow.’

b. *Object relative clause*
… HAVE-TO CHOOSE **GIRAFFE**$_i$ [$_{RC}$ PI$_i$ COW$_k$ $_k$LICK$_i$ _].
‘(You) have to choose the giraffe that the cow licks.’

c. *Filler*
… HAVE-TO CHOOSE ANIMAL WHITE BLACK.
‘(You) have to choose the black and white animal.’[11]

Experiments took place at the Université de Paris and at the Université de Nantes.

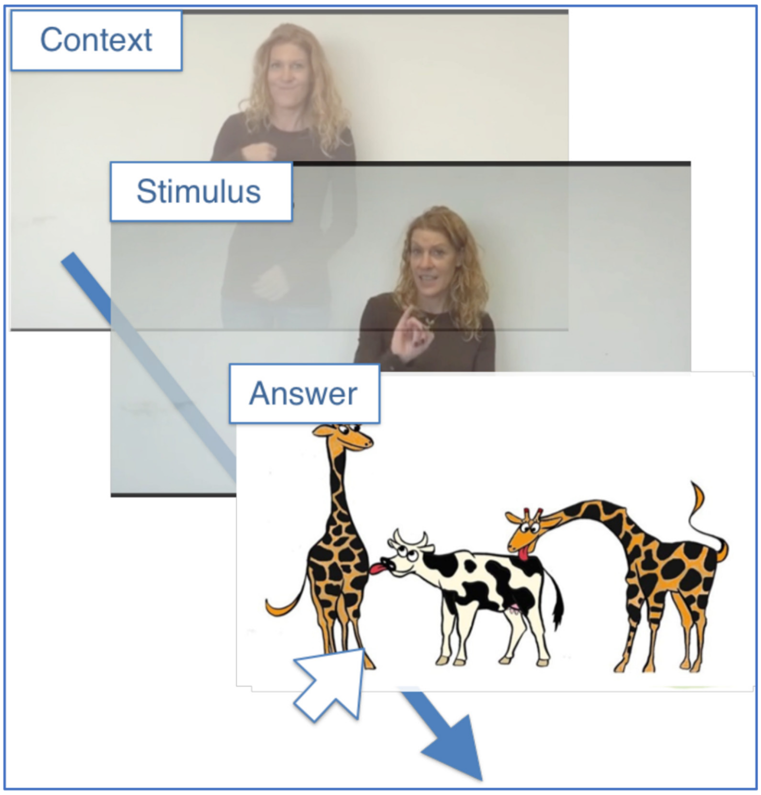


**Figure 11** Illustration of an item in LSF.

11 This is just an illustration. In the experiment, pictures used for target items are never used for fillers (but they have the same structure, with two identical characters interacting with a third, different one).

### 5.1.2 LIS

For the LIS experiment, each block contained 32 trials (10 subject RCs, 10 object RCs, 12 fillers) preceded by 3 training items (one example of each type of trial). The full list of items is given in the Appendix. The duration of each block was around 15 minutes and it was embedded in a larger testing session (1h) in which participants were undertaking other lexical and syntactic tests.

Participants were sitting in a bright room in front of a laptop with a 15'' screen and answered using the touch screen. For each trial, participants first saw the stimulus video (no context provided) accompanied by the corresponding small-size picture in the bottom left corner of the screen, and then the picture alone in the middle of the screen on which they could touch the correct character to provide their answer (see *Figure 12*). In half of the items the arrangement in space of the various arguments in the request sentence matched that of the various characters in the picture; in the other half, there was a clear mismatch. This pattern was adopted to avoid that the simultaneous presentation of a miniature of the picture and the stimulus video induce a topographical interpretation of the use of the signing space in the latter. The stimulus video consisted of a request embedding a subject RC (29a), an object RC (29b) or, if the item was a filler, a simpler sentence (29c) targeting the middle character.

(29) *LIS*

a. *Subject relative clause*
   [$_{RC}$ **CHILD**$_{K}$ MAN$_{J}$ CL$_{J}$ $_{K}$PUSH$_{J}$ PE$_{K}$] CLICK
   'Click on the child that pushes the man.'

b. *Object relative clause*
   [$_{RC}$ **CHILD**$_{k}$ CL$_{k}$ MAN$_{j}$ $_{j}$PUSH$_{k}$ PE$_{k}$] CLICK
   'Click on the child that the man pushes.'

c. *Filler*
   [CL TALLEST] CLICK
   'Click on the tallest (animal).'

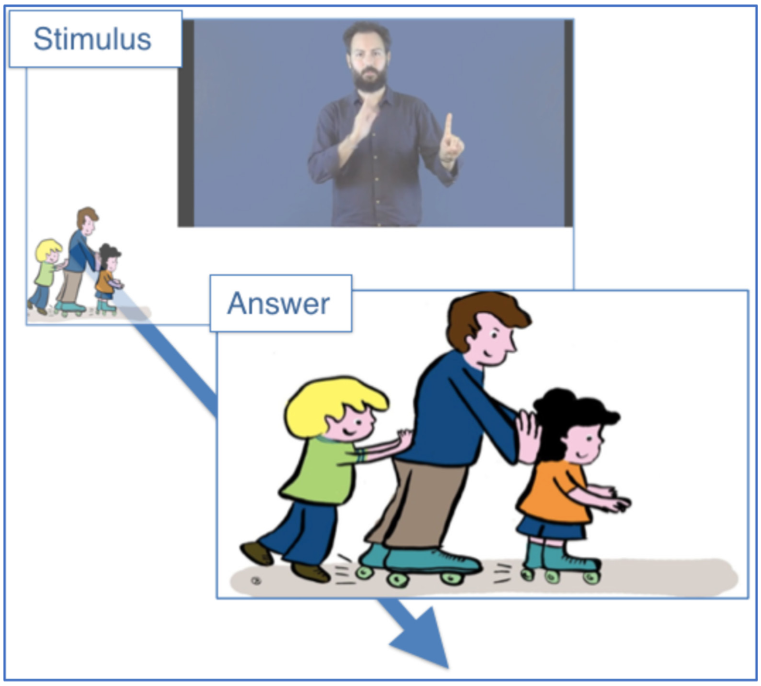


**Figure 12** Illustration of an item in LIS.

### 5.1.3 LSC

For the LSC experiment, each block contained 25 trials (10 subject RCs, 10 object RCs, 5 fillers) preceded by 2 trainings (one example of each type of relative clause). The full list of items is given in the Appendix. The duration of each block was around 15 minutes and was embedded in a larger testing session (3h30) in which participants undertook other lexical and syntactic tests.

Participants were left alone in the experiment room to perform the test on their own. They were sitting approximately 45 cm away from the screen (4:3 display, 22" screen) and answered using a mouse by clicking on the selected character.

For each trial, participants first saw the stimulus video (without context), then clicked on an arrow to transition to the answer picture where they could click on the correct character (see *Figure 13*).

To avoid that participants might interpret any spatial information included in the items topographically, i.e. as referring to the actual position of the characters in the picture rather than a grammatical representation arguments' reference and agreement relation, the picture was only made visible after the end of the recorded sentence. The stimulus video consisted in a request embedding a subject RC (30a) or an object RC (30b). Fillers were either subject RCs and object RCs targeting the middle character or simpler sentences without any embedding like (30c).

(30) *LSC*

a. *Subject relative clause*
$[_{RC}$ SAME **ELEPHANT**$_i$ $_i$SPLASH$_k$ BOY$_k$] IX$_2$ CLICK
'Click on the elephant that splashes the boy.'

b. *Object relative clause*
$[_{RC}$ SAME **ELEPHANT**$_i$ BOY$_k$ $_k$SPLASH$_i$] IX$_2$ CLICK
'Click on the elephant that the boy splashes.'

c. *Filler*
ANIMAL BLUE IX$_2$ CLICK
'Click on the blue animal.'

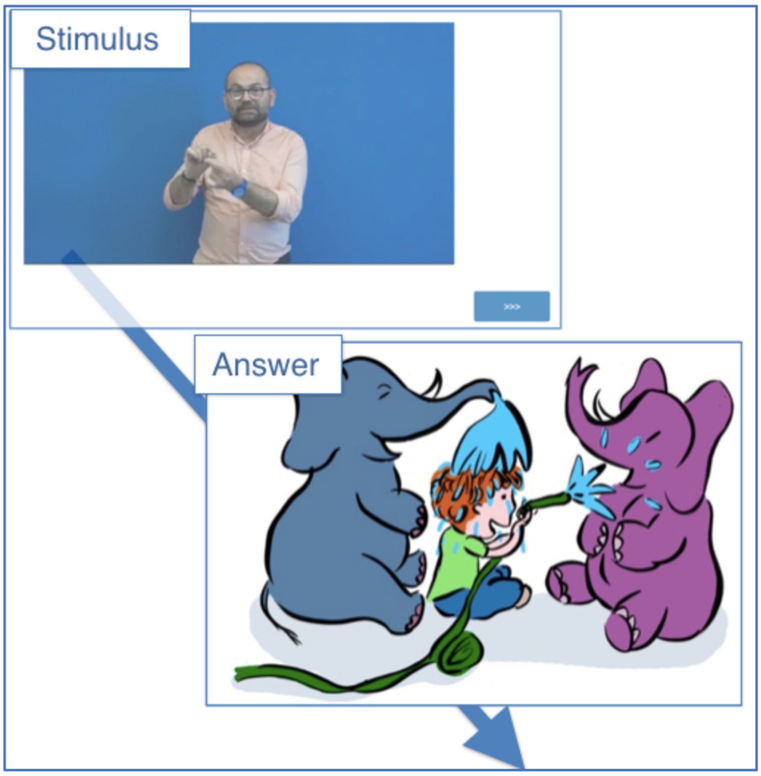


**Figure 13** Illustration of a filler in LSC.

## 5.2 Participants

Across all three sign languages, participants were mainly selected based on their hearing status (deafness had to be attested before 3 years of age) and the age at which they were first exposed to a sign language (no later than 15 y.o.). They were recruited either through social media (in France), through various associations for the Deaf in various cities (in Italy) or within the local Deaf community (Catalonia). They received a compensation of 50 euros (France, Catalonia) or

150 euros (Italy) for their participation in the complete battery of tests.[12] We collected metadata regarding their signing background through a questionnaire in sign language (AoE, existence of deaf relatives, modality of communication with parents, siblings, other relatives, type of education whether oralist, bimodal or mostly SL, etc…). The metadata were anonymized.

Additionally, participants had to perform a short, timed, Odd One Out Cognitive Task[13] to ensure that they were not presenting potential cognitive issues that would affect their performance. This test was made of 2 training items followed by 28 items in which four simultaneous tokens were presented, one of which did not fit the general pattern obeyed by the three others (i.e. an intruder, see ***Figure 14***).

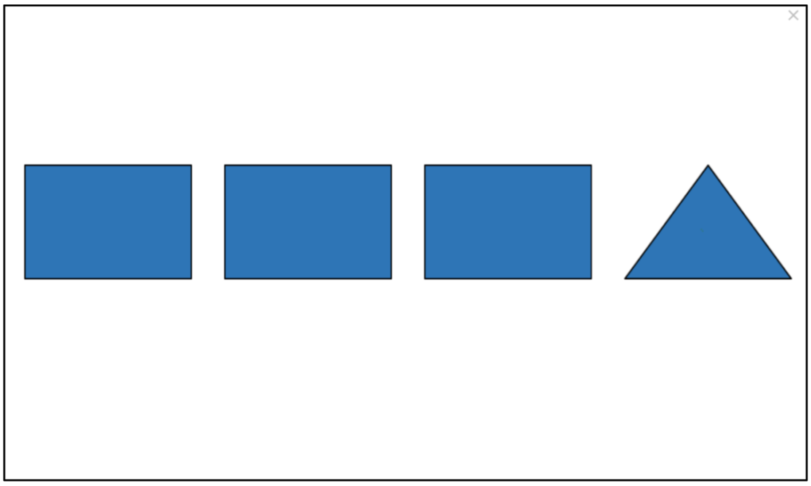

**Figure 14** Example of an item within the Odd-one out test.

Among the participants matching our inclusion criteria (i.e. hearing status, AoE and absence of detected cognitive impairment), we created three "language" groups, based on the age of first sign language exposure, what we call their language group:

**(i)** participants with deaf parent(s), exposed to a SL from birth (natives);

**(ii)** participants exposed before primary school (early learners, with an AoE ranging between 1 and 5 y.o.) and

**(iii)** participants exposed later, between 6 to 15 y.o. (late learners).

The distribution of signers across the different age groups slightly varies across the three sign languages. They are detailed below.

### 5.2.1 LSF

We collected data from 49 participants (40 in Paris and 9 in Nantes), out of which we excluded seven. One participant was excluded because they were not French, but Belgian, hence signing French-Belgian SL (LSFB); five were excluded due to their very late AoE to a sign language (after 15 y.o.), and one participant was excluded based on their low performance on fillers, with an accuracy below the 75% threshold. Among the 42 remaining participants, 13 were native LSF signers, 14 were early LSF signers and 15 were late LSF signers. Participants were aged between 19 and 72 years (mean = 36.95 y.o., *SD* = 9.31) and there were 23 women and 19 men.

### 5.2.2 LIS

We collected data from 44 participants, out of which we excluded five. One participant was excluded due to their very late AoE to a sign language (after 15 y.o.); one participant was excluded because they were postlingually deaf; one because of a poor performance in the

12 The battery of tests was longer in Italy, hence the higher compensation.

13 The cognitive test administered for the three language groups was the same, but is made accessible in the SIGN-HUB assessment tools platform as three different tests: COGONEOUTLSF (Aristodemo &Friedmann 2019) for LSF; COGONEOUTLIS (Giustolisi & Friedmann 2019) for LIS; COGONEOUTLSC (Zorzi, Sánchez Amat & Friedmann 2019) for LSC.

general cognitive task and two participants were excluded based on their low performance on fillers, with an accuracy below the 75% threshold. Among the 39 remaining participants (19 women, 20 men), 15 were native LIS signers, 13 were early LIS signers and 11 were late LIS signers. Participants were aged between 30 and 65 years (mean = 46.45 y.o., *SD* = 8.68).

### 5.2.3 LSC

We collected data from 42 participants at Pompeu Fabra University, out of which we excluded 8. One participant was excluded due to a low score in the cognitive test; one for technical problems in collecting their metadata; one due to their late AoE to LSC (after 15 y.o.), and five participants were not considered based on their low performance on fillers, with an accuracy below the 75% threshold. Among the 34 remaining participants (19 women, 15 men), 12 were native LSC signers, 11 were early LSC signers and 11 were late LSC signers. Participants were aged between 23 and 69 years (mean = 47.67 y.o., *SD* = 10.6).

# 6 Results and analyses

## 6.1 Accuracy

The analyses were realized on each sign language independently, but following the same scripts.[14] We had a binary dataset in which correct answers were coded as "1" and incorrect answers as "0". We started by conducting an item analysis to detect problematic items on which native signers performed below 50% on average. If the score obtained was due to a technical error, we removed the item in both blocks (the subject RC and object RC version of it). If no technical errors could explain the result, the items were kept. In LSF, this led to the removal of four items, hence leaving 48 items (24 subject RC and 24 object RC) to analyze. In LIS, three items were removed, hence leaving 34 items (17 subject RC and 17 object RC) within the analysis. In LSC, only one item had a technical issue such that we performed the analysis on the remaining 38 items (19 subject RC and 19 object RC).

Accuracy and error results were analyzed with the R software (R Core Team 2020) using generalized linear mixed models from the binomial family via the glmer function (package lme4, Bates et al. 2015). The independent variables were language group (native, early & late), condition (subject RC & object RC) and chronological age (as a continuous, mean centered corrected variable). Random variables were intercepts for participants and items.[15]

Using ANOVA, we started by comparing minimally different models (df = 1) in which one of the independent variables was removed to control for the overall impact of a given parameter in the data distribution. Keeping only relevant independent variables (more details within each language subsection), we then conducted pairwise comparisons using the package emmeans (Lenth 2020), to obtain finer grained information regarding differences between natives, early, and late learners in their understanding of subject RCs on one side, and of object RCs on the other side.

The results concerning accuracy are presented and analyzed separately for each language here after, error results are presented in Section 5.2.

### 6.1.1 LSF

Accuracy in LSF is illustrated in ***Figure 15***.

In LSF, models including chronological age as a variable did not provide a better fit of the data, so we removed this parameter from the independent variables of the model ($\chi2(1) = 3.13$, $p = 0.07699$). Language group ($\chi2(2) = 8.06$, $p = 0.01775$), condition ($\chi2(1) = 346.16$, $p < 0.0001$) and the interaction between these two factors ($\chi2(2) = 8.96$, $p = 0.01134$) were significant. All pairwise comparisons using the resulting generalized mixed model across language group (natives, early, late) and condition (SRC, ORC) are presented in ***Table 1***.

14 Available for consultation here: *https://osf.io/5bdu2/?view_only=683792bb06d2410facb49037a02a85b5*.

15 Example of the maximal model formula: glmer(Value~condition*Group*Age_c + (1|ID.participant) + (1|Item), data = Dataset, family=binomial).

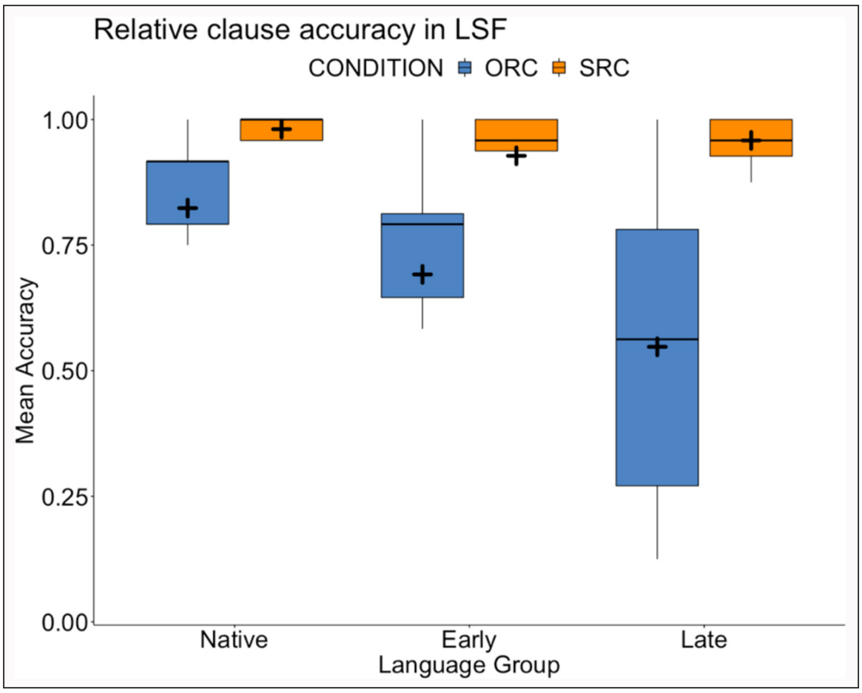


**Figure 15** Accuracy in object (blue) and subject relative clause (orange) comprehension in LSF, for native (left, n = 13), early (middle, n = 14) and late (right, n =15) learners. Black crosses represent the mean, and black horizontal lines represent the median of each group. The whiskers extend to the nearest data point that is no more than 1.5 times the Inter Quartile Range from the hinges.

Each line in *Table 1* presents the estimate, standard error, z-ratio and p-value associated with the use of the model to compare the two datasets referred to in the corresponding row. For example, the first row displays the value of the parameters obtained when comparing the score realized by native signers in subject relative clauses accuracy to their performance in object relative clauses.

**Table 1** Pairwise comparison of accuracy across language group (native, early, late) and conditions (SRC, ORC), using generalized mixed model and the binomial family in LSF.

| Comparison | | | | |
|---|---|---|---|---|
| **By condition** | **Est.** | **SE** | **z** | **p** |
| **Native SRC vs. Native ORC** | **−3.374** | **0.544** | **−6.204** | **<.0001** |
| **Early SRC vs. Early ORC** | **−2.410** | **0.286** | **−8.419** | **<.0001** |
| **Late SRC vs. Late ORC** | **−3.659** | **0.337** | **−10.861** | **<.0001** |
| **Population Natives vs. Early** | **Est.** | **SE** | **z** | **p** |
| **Native SRC vs. Early SRC** | **1.891** | **0.766** | **2.467** | **0.0136** |
| Native ORC vs. Early ORC | 0.927 | 0.557 | 1.664 | 0.0961 |
| Population Natives vs. Late | Est. | SE | z | p |
| Native SRC vs. Late SRC | 1.433 | 0.790 | 1.814 | 0.0697 |
| **Native ORC vs. Late ORC** | **1.719** | **0.563** | **3.053** | **0.0023** |
| **Population Early vs. Late** | **Est.** | **SE** | **z** | **p** |
| Early SRC vs. Late SRC | −0.458 | 0.631 | −0.725 | 0.4682 |
| Early ORC vs. Late ORC | 0.792 | 0.532 | 1.489 | 0.1365 |

To help the reader better understand how to interpret all these values, significant differences are in bold font.

The table shows that for all three groups the difference between subject RCs and object RCs was significant, such that subject RCs were better understood. In the comprehension of object RCs, natives performed significantly better than late learners. For completeness sake: native signers outperformed early signers in understanding subject RCs.

### 6.1.2 LIS

Accuracy in LIS is shown in *Figure 16*.

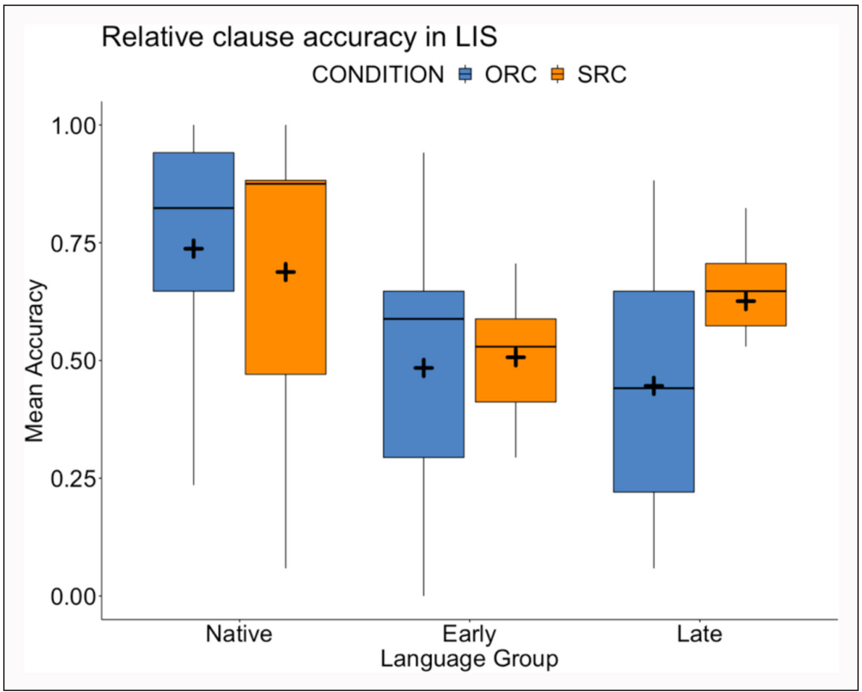


**Figure 16** Accuracy in object (blue) and subject relative clause (orange) comprehension in LIS (n= 39), for native (left, n = 15), early (middle, n = 13) and late (right, n = 11) learners. Black crosses represent the mean, and black horizontal lines represent the median of each group. The whiskers extend to the nearest data point that is no more than 1.5 times the Inter Quartile Range from the hinges.

In LIS, the presence/absence of the factor of chronological age did not impact the general fit of the data ($\chi2(1) = 1.35$, $p = 0.245$). On the other hand, language group ($\chi2(2) = 7.18$, $p < 0.001$) and its interaction ($\chi2(2) = 14.6$, $p < 0.0001$) with condition, significant in itself ($\chi2(1) = 3.30$, $p < 0.01$), were both significant. LIS presents more widespread distributions, which do not allow for the identification of a general Subject Advantage in this language. All pairwise comparisons are presented in *Table 2*. Significant differences are in bold font.

**Table 2** Pairwise comparison of accuracy across language group (native, early, late) and conditions (SRC, ORC), using generalized mixed model and the binomial family in LIS.

| **Comparison** | | | | |
|---|---|---|---|---|
| **By condition** | **Est.** | **SE** | **z** | **p** |
| Native SRC vs. Native ORC | 0.321 | 0.226 | 1.422 | 0.1551 |
| Early SRC vs. Early ORC | −0.106 | 0.205 | −0.516 | 0.6061 |
| **Late SRC vs. Late ORC** | **−0.864** | **0.220** | **−3.920** | **0.0001** |
| **Population Natives vs. Early** | **Est.** | **SE** | **z** | **p** |
| **Native SRC vs. Early SRC** | **0.995** | **0.430** | **2.313** | **0.0207** |
| **Native ORC vs. Early ORC** | **1.422** | **0.434** | **3.276** | **0.0011** |
| **Population Natives vs. Late** | **Est.** | **SE** | **z** | **p** |
| Native SRC vs. Late SRC | 0.420 | 0.441 | 0.951 | 0.3414 |
| **Native ORC vs. Late ORC** | **1.605** | **0.444** | **3.615** | **0.0003** |
| **Population Early vs. Late** | **Est.** | **SE** | **z** | **p** |
| Early SRC vs. Late SRC | −0.575 | 0.447 | −1.288 | 0.1979 |
| Early ORC vs. Late ORC | 0.183 | 0.445 | 0.411 | 0.6808 |

In LIS, we observe that natives significantly outperformed early learners in subject RCs, and that they outperformed both early and late learners in object RCs. The difference between early and late learners was not significant. The only population in which we observed a Subject Advantage is late learners, where we see a significant difference between subject RCs and object RCs.

### 6.1.3 LSC

In Catalan Sign Language yet another pattern emerged, as can be seen in ***Figure 17***.

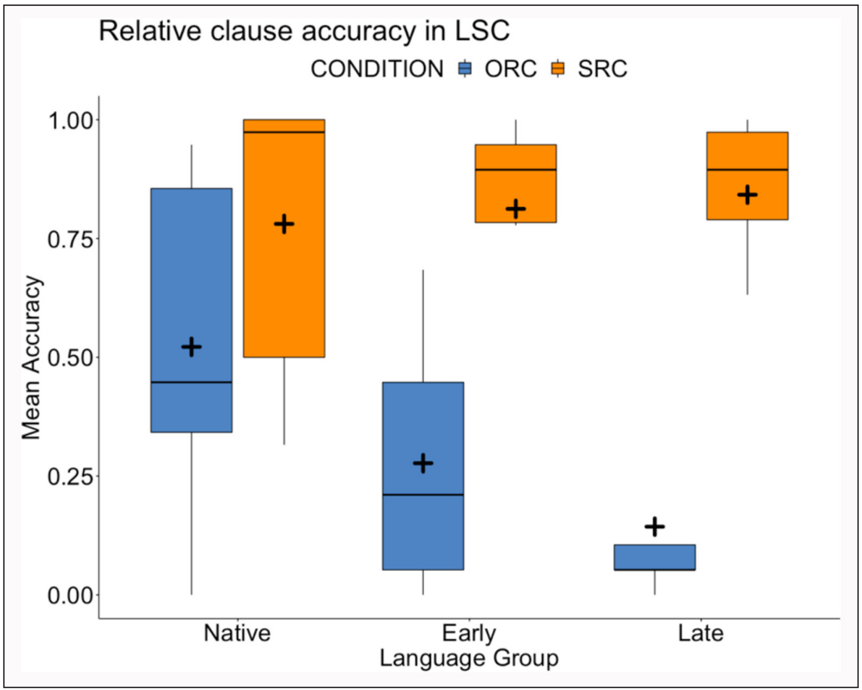


**Figure 17** Accuracy in object (blue) and subject relative clause (orange) comprehension in LSC, for native (left, n = 12), early (middle, n = 11) and late (right, n = 11) learners. Black crosses represent the mean, and black horizontal lines represent the median of each group. The whiskers extend to the nearest data point that is no more than 1.5 times the Inter Quartile Range from the hinges.

In LSC, the factors of chronological age ($\chi2(1) = 9.23$, $p < 0.001$) and its interaction ($\chi2(1) = 27.9$, $p < 0.0001$) with condition were both significant. Similarly, condition ($\chi2(1) = 388.61$, $p < 0.0001$) and its interaction ($\chi2(2) = 44.46$, $p < 0.0001$) with language group (which, taken alone, is not predictive of the data distribution, $\chi2(2) = 0.75$, $p = 0.6861$), were significant, as can be seen very clearly in the graph in ***Figure 17***. This language seems to present a strong Subject Advantage that increases with age of exposure to LSC. All pairwise comparisons highlighting the language group by condition interaction are presented in ***Table 3***. Significant differences are in bold font.

**Table 3** Pairwise comparison of accuracy across language group (native, early, late) and conditions (SRC, ORC), using generalized mixed model and the binomial family in LSC.

| **Comparison** | | | | |
|---|---|---|---|---|
| **By condition** | **Est.** | **SE** | **z** | **p** |
| **Native SRC vs. Native ORC** | **−1.605** | **0.250** | **−6.433** | **<.0001** |
| **Early SRC vs. Early ORC** | **−2.736** | **0.267** | **−10.236** | **<.0001** |
| **Late SRC vs. Late ORC** | **−4.316** | **0.361** | **−11.954** | **<.0001** |
| **Population Natives vs. Early** | **Est.** | **SE** | **z** | **p** |
| Native SRC vs. Early SRC | −0.368 | 0.521 | −0.707 | 0.4795 |
| Native ORC vs. Early ORC | 0.762 | 0.502 | 1.520 | 0.1285 |
| **Population Natives vs. Late** | **Est.** | **SE** | **z** | **p** |
| Native SRC vs. Late SRC | −1.003 | 0.554 | −1.810 | 0.0703 |
| **Native ORC vs. Late ORC** | **1.708** | **0.553** | **3.088** | **0.0020** |
| **Population Early vs. Late** | **Est.** | **SE** | **z** | **p** |
| Early SRC vs. Late SRC | −0.634 | 0.520 | −1.219 | 0.2229 |
| Early ORC vs. Late ORC | 0.946 | 0.520 | 1.818 | 0.0691 |

In LSC, the Subject Advantage was significant across all three groups. When it comes to object RCs, late learners had a significantly lower performance than native learners. The difference

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between late and early learners only approaches significance, while there is no significant difference between natives and early learners.

Regarding chronological age, it does not interact with language group but it does impact the performance on conditions, as can be seen in the effect plot in *Figure 18*.[16] The plot shows how the score is affected by the Age variable, which has been scaled and centered, in the object relative clause condition (left panel) and in the subject relative clause condition (right panel). We see that the impact of Age is greater in object RCs than in subject RCs, since the performance is sharply decreasing as age increases.

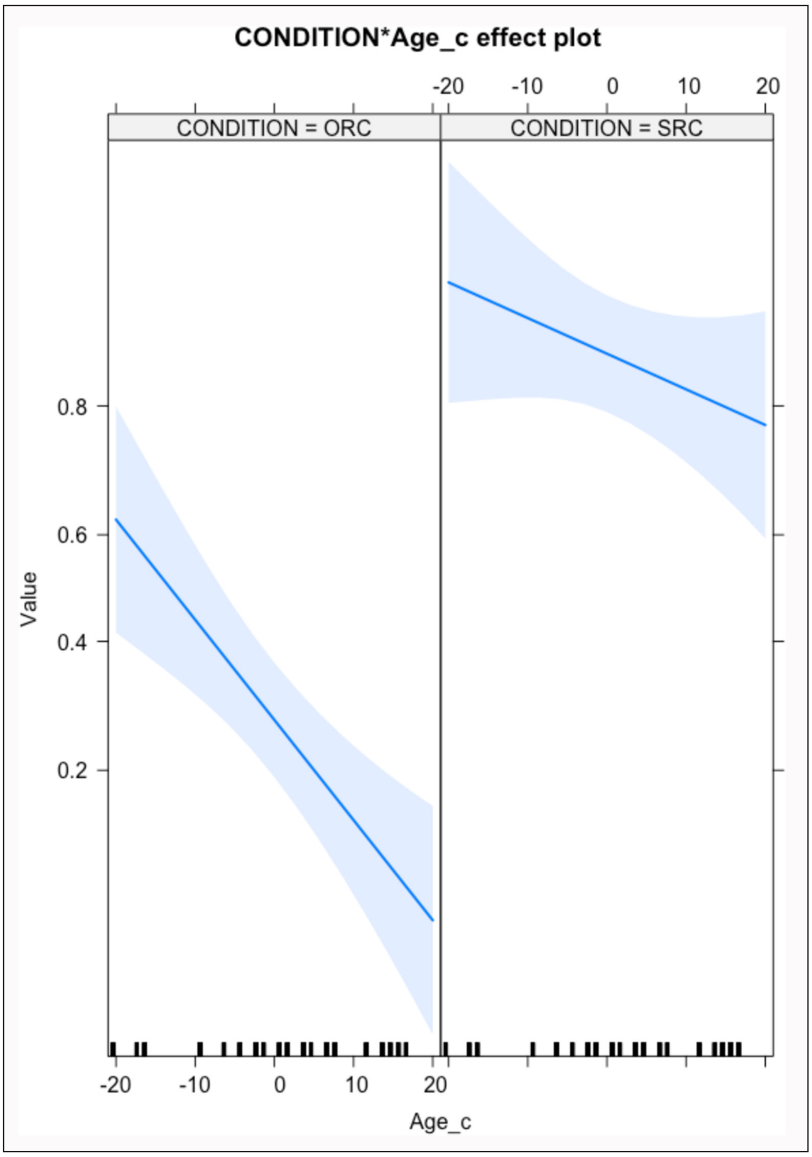


**Figure 18** Plot of the effect of the interaction between Age and Condition on the accuracy within ORC (left) and SRC (right) in LSC. On the x axis, Age has been scaled and centered.

### 6.1.4 Summary of accuracy results

As for externally headed RCs, we found a clear Subject Advantage in all three LSF populations. This Subject Advantage interacted with language group; with a greater difference in non-native compared to native signers in the comprehension of subject RCs vs. object RCs.

As for internally headed RCs, results were more difficult to summarize. In LIS only late learners displayed a Subject Advantage, while no bias towards either subject RCs or object RCs surfaced in the performance of natives and early learners. In LSC, non-native signers (early and late learners) were below chance[17] when it came to object RCs, suggesting that they systematically interpreted them as subject RCs. We shall discuss below (§6.4) what the implications of these

16 We used the library(effects) and the function "plot(allEffects())" (Fox & Weisberg 2019).

17 In this study, since there were three characters in the pictures, the chance level is around 30%.

results might be for the grammar(s) of LSC. The mean accuracy in subject RCs tended to be slightly higher in early and native signers, although the difference was not significant. The two data sets concorded in suggesting a strong subject bias in this language.

Before discussing the relevance of these results and drawing any general conclusions, however, it is essential to also conduct an analysis on the type of errors that were made by the participants across groups and conditions.

## 6.2 Error analysis

Remember that internally headed RCs involve a further complexity that is independent from the subject RCs vs object RCs contrast, that of determining the head which is not explicitly marked through a fixed position. The design of our experiment allows us to tease apart these two difficulties. Participants had the choice between three characters. Hence there were two types of possible errors: (1) participants could click on the wrong side character, which meant they correctly identified the head but not its function within the RC (subject RCs vs object RCs); or (2) participants could click on the middle character, which meant they misunderstood which was the head of the RC (e.g interpreting the stimulus 'the giraffe that the cow is licking' as 'the cow that is licking the giraffe').

Since LSF presents externally headed RCs, the head is always identified by its position on the left of the RC. We thus expect participants to make few errors concerning head identification (few clicks on the middle character), and more errors concerning the gap position, i.e. many clicks on the wrong side characters. This latter type of errors should be more frequent in object RCs due to the Subject Advantage.

In LIS and LSC, on the other hand, since the head is internal, we expect participants to have troubles identifying it and hence they should make more errors clicking the middle character, independently from the subject RCs or object RCs condition. If there is also a Subject Advantage, we expect the distribution of errors concerning only the side character to depend on the subject RCs/object RCs condition, with more errors of this kind in object RCs.

All the analyses have been realized on each sign language independently, following the same procedure. We have created a subset of the data only containing the wrong answers in the object RCs condition. We have a binary dataset in which answers targeting the middle character were coded as "1" and answers targeting the left/right character were coded as "0". This was our dependent variable.

The independent variables were language group (native, early & late), condition (SRC & ORC), and chronological age. We again controlled for relevant parameters and their interactions by conducting ANOVA analysis across minimally different models. Random variables were intercepts for participants and items, except for LSF whose model only had "items" as a random effect (instead of both "items" and "participants"). The great disparity across participants' error figures, with some presenting only one datapoint in SRC, did not leave enough data against which to test for an effect of the participant variable. The results concerning error patterns in the two conditions are discussed separately for each language.

### 6.2.1 LSF

In LSF, models including chronological age as a variable did not provide a better fit of the data, so we removed this parameter from the independent variables of the model ($\chi 2(1) = 2.24$, $p = 0.1341$). The effect of condition approached significance ($\chi 2(1) = 2.97$, $p = 0.0846$), language group had an impact on the data distribution ($\chi 2(2) = 25.05$, $p < 0.0001$) and the interaction between the two parameters was not significant ($\chi 2(2) = 3.362$, $p = 0.1862$). We see in *Figure 19* that the type of errors made in subject RCs are equally distributed between the head noun and the position of the gap for all three populations. In object RCs however, a different pattern seems to emerge for late signers, who present a larger proportion of mistakes targeting the side character than those targeting the middle character. This difference in pattern is significantly different from native signers (Est. = –1.37, SE = 0.34, $p < 0.0001$) and from early signers (Est. = –1.08, SE = 0.27, $p < 0.0001$), while the latter two do not differ between them (Est. = 0.29, SE = 0.33, $p = 0.3779$).

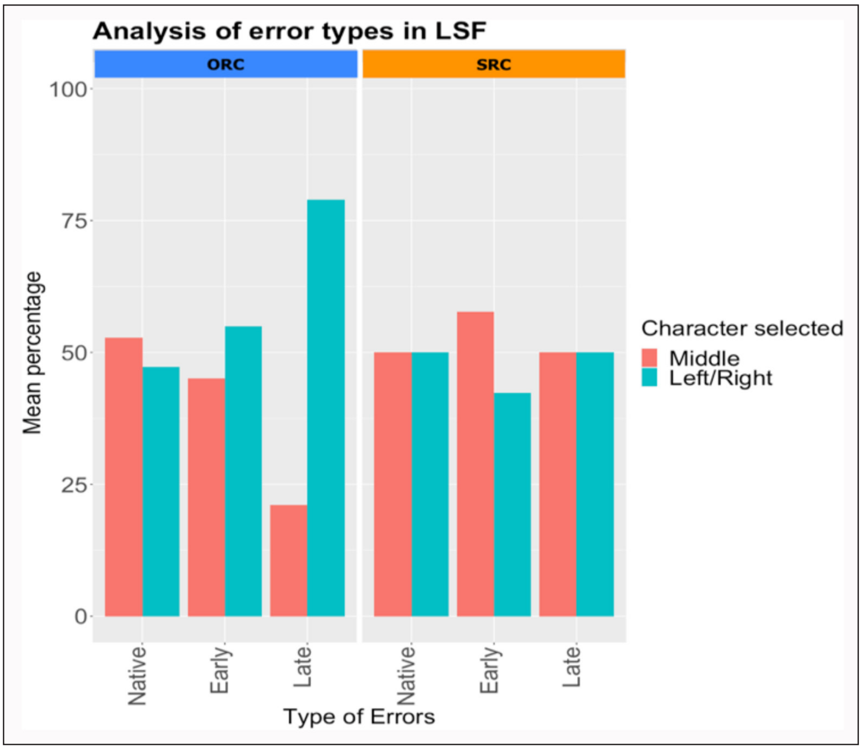


**Figure 19** Proportion of clicks on the competing head noun (middle character), and on the competing gap (left/right characters) in errors for object RC (left panel) and subject RC (right) in LSF. Comparison between natives (left), early (middle) and late (right).

### 6.2.2 LIS

In LIS, the factor of chronological age did not provide a better fit when integrated in the model ($\chi 2(1) = 0.66$, $p = 0.4164$) and was thus removed. Condition ($\chi 2(1) = 0.15$, $p = 0.6966$) and language group ($\chi 2(2) = 1.98$, $p = 0.3724$), as well as their interaction ($\chi 2(2) = 1.82$, $p = 0.4025$) did not had any impact either, confirming what was already visible graphically in *Figure 20*. As expected, errors target mainly the middle character, the competing head noun (68.,5% of the errors) independently from the conditions or the language groups.

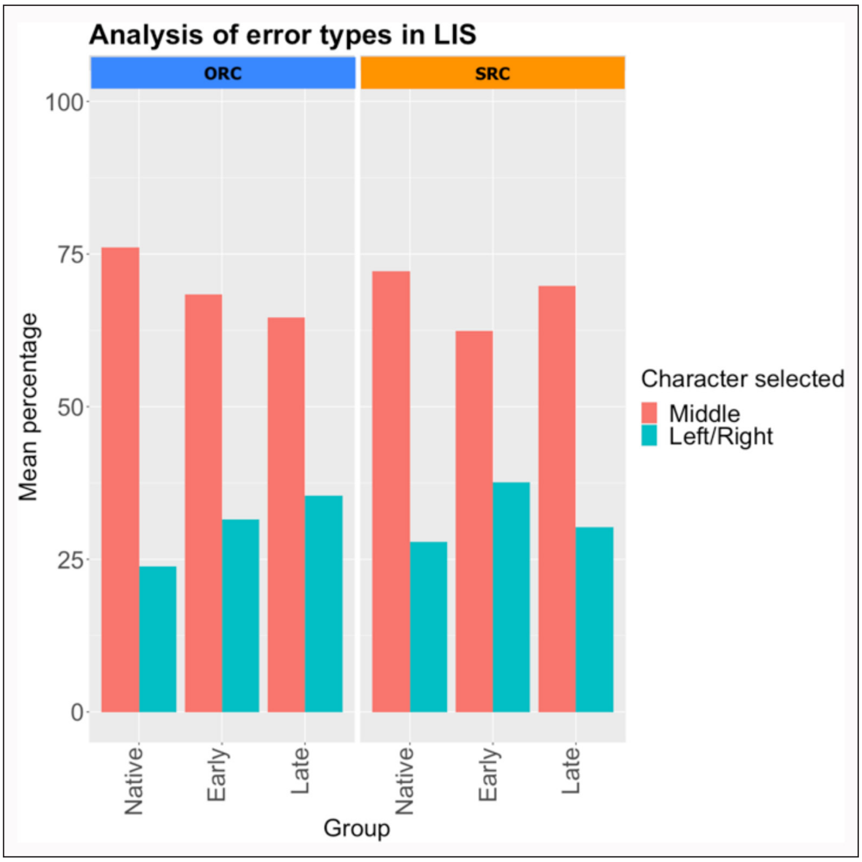


**Figure 20** Proportion of clicks on the competing head noun (middle character), and on the competing condition (left/right) in errors for object RCs (left panel) and subject RCs (right) in LIS. Comparison between natives (left), early (middle) and late (left) learners.

### 6.2.3 LSC

In LSC, the factor of chronological age did not play a role in the data distribution of error types ($\chi 2(1) = 1.38$, $p = 0.2393$), similarly, the factor of language group ($\chi 2(2) = 3.28$, $p = 0.2194$) and its interaction with condition ($\chi 2(2) = 2.15$, $p = 0.3407$) did not affect the fit. We thus only kept the factor of condition as an independent variable, since it was the only parameter affecting the data distribution significantly ($\chi 2(1) = 26.01$, $p < 0.0001$). With the resulting model, we obtain a significant difference between subject RCs and object RCs (Est. = 1.46, SE = 0.3, $p < 0.0001$).

When we look at ***Figure 21***, we indeed see that, in subject RCs, all participants (native, early and late) patterned like LIS participants: most errors were of head identification (the middle character represents 78% of errors in subject RCs).

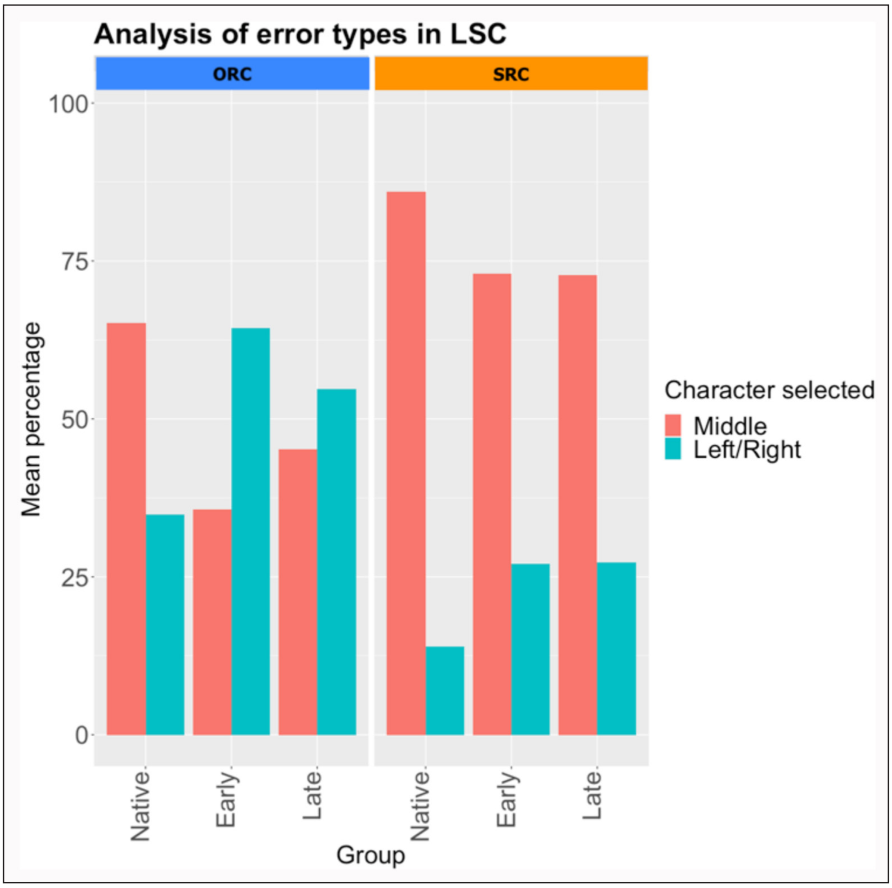


**Figure 21** Proportion of clicks on the competing head noun (middle character), and on the competing condition (left/right) in errors for object RCs (left panel) and subject RCs (right) in LSC. Comparison between natives (left), early (middle) and late (right) learners.

In object RCs, however, a difference between natives on the one side and early learners on the other side arose. Native learners present a pattern that is very similar to what we observed with subject RCs: around 62% or errors were of head identification (middle character). Early learners, on the other hand, present a pattern that is similar to what is observed in LSF, with most errors regarding the identification of the function of the head (60% of errors targeting the side characters). The difference between Native ORC error pattern and Early ORC error pattern is significant (Est. = –1.39, SE = 0.65, $p = 0.0341$).

## 7 Discussion

In this paper we had three main research objectives: i) investigate whether the Subject Advantage in the comprehension of RCs extends across modalities; ii) investigate whether a delayed exposure to (sign) language may impact RC comprehension in adult signers; iii) investigate whether the Subject Advantage emerges across relativization strategies, in internally headed RCs as well as in externally headed RCs. In this section we discuss our results relative to these questions and comment on some interesting differences that emerged between LIS and LSC.

### 7.1 Does the Subject Advantage in RCs comprehension extend across modalities?

The answer to this question is straightforward. We found that externally headed relative clauses present a Subject Advantage across modalities. LSF behaves exactly like other languages that display externally headed relatives, exhibiting a strong Subject Advantage, hence confirming the results reported by Hauser & Pozniak (2019). The Subject Advantage interacts with language group: in LSF, even if it is observable across groups, it is strongest in late learners. In LSC the Subject Advantage is also present in all three groups, and the strength of the effect increases with the age of exposure. In LIS, the Subject Advantage is significant only in the late group.

### 7.2 Does delayed exposure to (sign) language impact RC comprehension in adult signers?

The answer to this question is also straightforward: the Subject Advantage is modulated by age of exposure. As we summarized in 6.1, the later the exposure, the stronger the Subject Advantage. That difficult structures are more affected by age of exposure is in line with the literature (Emmorey & Corina 1990; Mayberry 1993; Emmorey et al. 1995; Boudreault & Mayberry 2006; Cormier et al. 2012) and with new further evidence by our research group (Authors, under review).

### 7.3 Does the Subject Advantage emerge across relativization strategies?

As for the third research question concerning internally headed RCs, the pattern of results that we found requires a detailed discussion. As expected, we found that it is more difficult to identify the head in internally headed RCs than in externally headed RCs. In LSC and LIS, more errors were made regarding the identification of the head noun (i.e. participants hesitated between the correct head noun and the middle character), while the opposite pattern was found in LSF, where signers made more mistakes of gap identification, hence targeting the wrong peripheral character.

The result that was most difficult to anticipate (and potentially the most interesting) is the existence of a Subject Advantage in the comprehension of internally headed RCs, which is observable both in LIS and in LSC although to a different degree. In LIS, this Subject Advantage is statistically significant only in late learners, while in LSC it is visible in all three acquisition groups. We think that this result can contribute indirect evidence both on the debate about the source of the Subject Advantage in RCs in general, and for the syntactic analysis to be given to internally headed RCs.

As for the debate about its source, the fact that the Subject Advantage is attested despite the absence of a gap in internally headed RCs is a powerful argument against all approaches that explain the Subject Advantage in languages like English as a reflex of shorter retention of the subject gap in the memory buffer given its vicinity to the relative clause head. Similarly, the presence of a Subject Advantage in internally headed RCs is also a challenge for any explanation that reduces it to a canonicity effect. Swinney, Prather & Love (1996) and Sekerina (2003) suggest that the language processor employs a canonical sentence schema to interpret sentences. Thus, structures in a language's canonical word order (like subject relatives in English) are assumed to be easier to process than structures with a non-canonical order (like object relatives in English or in LSF). Crucially, both subject and object RCs follow the canonical word order in LIS and LSC and, this notwithstanding, a difference emerges between them. Therefore, the Subject Advantage is not likely to be a canonicity effect.

The type of explanation that seems to be best suited to explain the Subject Advantage in internally headed RCs is the account that assumes that (i) there is a processing cost when the subject intervenes hierarchically between the object and its gap (cf. Friedmann et al. 2009 for this explanation of the Subject Advantage) and (ii) the gap that is not visible in overt syntax is created by covert movement of the RC head (cf. Cole, 1987 a.o. for this approach to internally headed RCs).

We acknowledge that with internally headed RCs, namely in LIS and LSC, the Subject Advantage was especially (or only) significant in late learners or non-native populations. Remember that our experiment is an off-line sentence-to-picture matching task and we

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measured only accuracy, therefore we cannot exclude that a Subject Advantage could emerge even with native LIS and LSC signers with a more sensitive on-line task. Still, it is true that the same off-line task revealed in LSF a Subject Advantage in all groups of signers, including natives. This crosslinguistic difference may suggest that the effect is stronger in externally headed RCs than in internally headed RCs. Notice that this is coherent with the acquisition pattern observed in Korean, where internally headed RCs emerge earlier than externally headed RCs and might perhaps explain the Object Advantage observed in Wenzhounese (Hu Shenai et al. 2018). The modulation of the Subject Advantage might also indicate that the two factors mentioned above (canonicity effects and presence versus absence of an overt gap) might play a secondary role, adding to the main effect due to hierarchical subject intervention in object dependencies.

As we mentioned, the Subject Advantage in internally headed RCs provides indirect evidence in favor of a certain kind of analysis of this structure, one that assumes a covert movement of the head. This has an important consequence: if we are right, the Subject Advantage, an effect observable in comprehension that is easily measurable with experimental methods, can be used as a reliable, if indirect, diagnostic for LF movement. As such, it could be used in addition to islands effects (traditionally employed to argue for a covert movement analysis of wh-in situ at least since Huang Charles 1982) in all those cases where a covert dependency is argued for and needs to be detected (cf. also Xiang Ming et al. 2014; 2015 for experiments aiming at other direct processing evidence for this covert dependency). This is an interesting case of cross-modal interaction in which a diagnostic detected in a sign language can be extended to the analysis of spoken languages having the same abstract configuration.

### 7.4 Comparing LIS and LSC

LSC and LIS did not yield identical results while both displaying internally headed RCs, and both exhibiting a Subject Advantage. In LIS only late learners display a significant Subject Advantage, while native and early learners appear to have a good comprehension of both subject and object RCs. In LSC, the Subject Advantage is visible across all signers, with a clear distinction between native and non-native comprehension of object relative clauses.

We might wonder here about the source of this difference. There are two possible ways to go. One is related to a methodological difference between the two experiments and the other concerns a grammatical difference between the two languages.

Comparing the design between the two experiments, we observe that, while in the LIS experiment, the sentence was shown *together* with a miniature of the response picture, this was never the case in LSC, where the sentence was shown *before* the picture. It could be the case that the simultaneous exposure to the picture and the sentence induce LIS participants to a direct (non-structurally mediated) mapping between position of the sign in the neutral space and position of the corresponding character in the picture. Notice however that this is not likely, because the LIS team controlled the possible mapping between spatial organization of the signs in the sentence and that of the characters in the picture: while in half of the items, the loci associated to the arguments in the sentence indeed matched the positions associated with the characters in the response picture, the other half of the items displayed a systematic mismatch between grammatical space and the disposition of the characters in the picture. Had the participants relied on such a topographical mapping, they would have made many more mistakes in general, and crucially more than in the LSC experiment, where any topographical mapping was discouraged by the non-simultaneous display of the sentence and the picture. This means that the explanation of the difference between LSC and LIS data has to be found elsewhere.

Turning to the linguistic side, the internal make up of internally headed RCs in the two languages is different, in a way that might contribute to explaining the differences we observe in comprehension data.

In LIS, the relative marker PE obligatorily agrees in space with the internal head in LIS, as shown in the object relative clause (23) visually represented in ***Figure 6***, repeated below as ***Figure 22***.

[$_{RC}$ GIRAFFE$_a$ CL$_{ai}$ COW$_b$ $_b$LICK$_i$ PE$_i$ $_{\text{HOLD-CL}_i}$] CLICK$_a$

'Click on the giraffe that the cow licks.'

**Figure 22** Screen captures of the sentence (23), an object relative clause in LIS.

In *Figure 22* the relative PE points towards the locus in space associated with the object classifier co-referring with the giraffe, which is the (topicalized) head of the RC. Participants are likely to rely on this spatial agreement information to interpret the RC.

No such explicit spatial agreement is displayed in LSC relative clauses, where the relative marker MATEIX ('SAME') is articulated on the body. As can be observed in *Figure 9*, repeated here as *Figure 23*, corresponding to the object RC (27), the association between the relative marker SAME and the head (GIRAFFE in the example) is only signaled through a light head tilt and body turn.

[$_{RC}$ SAME GIRAFFE$_a$ COW$_b$ $_b$LICKa] IX$_2$ CLICK

'Click on the giraffe that the cow licks.'

**Figure 23** screen capture of the sentence in (27), an object relative clause in LSC.

On the other hand, in this example the relative element SAME sits close to the (topicalized) head of the RC, and participants are likely to use the linear proximity to identify the head of the RC. This cue is however less reliable than spatial agreement in LIS since the position of SAME is not systematically adjacent to the RC head in LSC grammar (Mosella Sanz 2012), even if this was its position in our data set. We speculate that this difference in the grammar of the two languages, and in particular the absence of a grammatical marker of the head, like spatial agreement, explains why the Subject Advantage is stronger in LSC: in the absence of a univocal cue identifying the head of the RC, participants are more prone to follow their bias towards a subject interpretation.

If we look now closer to LSC, we find that the Subject Advantage is so strong as to take the shape of a categorical difference between the grammar of native signers and that of non-native signers who systematically misunderstand object relative clauses.

The accuracy and error data that we observed are compatible with the hypothesis that native signers have both subject RCs and object RCs in their grammar while non-native signers do not allow object RCs at all in LSC. This configuration offers yet another illustration of the Accessibility Hierarchy and its Primary Relativization Constraint corollary (Keenan & Comrie 1977), which states that:

1. A language must have a primary RC-forming strategy.
2. If a primary strategy in a given language can apply to a low position on the Accessibility Hierarchy, then it can apply to all higher positions.
3. A primary strategy may cut off at any point on the Accessibility Hierarchy.

The LSC situation appears to comply with the Primary Relativization Constraint: (1) is verified since all signers of LSC understand subject RCs; (2) is verified since native signers, who understand object RCs, also understand subject RCs and (3) points towards two different grammars between native and non-native signers: the native grammar cuts off the Accessibility Hierarchy after object RCs, while the non-native grammar cuts it off right after SRCs. The fact that different varieties of the same language realize different steps of the Accessibility Hierarchy should not come as a surprise given the exceptional circumstances of access to language experienced by a large part of the deaf population. In fact, this finding, which replicates language internally the conclusion based on the typological literature, appears as an extreme case of AoE effect.

## 8 Conclusion

This article sheds new light on the cross-modality and cross-typology biases that affect relative clause comprehension, showing that a) the Subject Advantage described by Keenan & Comrie's Accessibility Hierarchy (1977) holds also for sign languages and b) it extends across relative constructions, affecting in particular an understudied relativization strategy, internally headed relative clauses. Altogether the results of our study confirm the validity of a structural approach to asymmetries in relative clauses comprehension, as well as the importance of the Subject Advantage as a diagnostic for long distance dependencies, be they overt or covert. As for the impact of age of exposure, we confirmed that native signers outperform non-native signers and that delay in language exposure significantly affects adults' language competence. We found that non-native signers exhibit a stronger Subject Advantage in the three sign languages we investigated, and that this takes the form of a categorial grammatical difference in LSC, where the language of non-native signers appear to lack object relativization.

## Data Accessibility Statement

All the video items used in the experiments and the scripts for the analyses can be found in the following OSF repository: *https://osf.io/5bdu2/?view_only=683792bb06d2410facb49037a02a85b5*. Images can be consulted by contacting the corresponding author. The detailed list of items if provided here after.

## Abbreviations

ACC = accusative, a.o = among others, AoE = Age of First Exposure; ASL = American Sign Language, bt = body turn, CL = classifier, DGS = German Sign Language (*Deutsche Gebärdensprache*), df = degrees of freedom, EEG = electroencephalogram, fMRI = functional magnetic resonance imaging, GEN = genitive, HKSL = Hong Kong Sign Language (香港手語), ICED = International Congress for the Education of the Deaf, JSL = Japanese Sign Language (日本手話, *Nihon Shuwa*), LAN = Left Anterior Negativity, Libras = Brazilian Sign Language (*Língua de Sinais Brasileira*), LIS = Italian Sign Language (Lingua dei Segni Italiana), LOC = locative, LSC = Catalan Sign Language (*Llengua de Signes Catalana*), LSF = French Sign Language (*Langue des Signes Française*), LSFB = French Belgian Sign Language (*Langue des Signes Belge Francophone*), NOM = nominative case, OPART = object partitive, ORC = object relative clause, PET = positron emission tomography, PL = plural, RC(s) = relative clause(s), re = raised eyebrows, rel = non-manual markers associated with relative clauses, rg = right gaze, SD = standard deviation, SG = singular, SL = sign language, SOV = subject object verb, SPART = subject partitive, SRC = subject relative clause, SVO = subject verb object, TİD = Turkish Sign Language (*Türk İşaret Dili*), TOP = topic, y.o. = years old.

## Additional file

The additional file for this article can be found as follows:

- **Appendix.** Material. DOI: *https://doi.org/10.5334/gjgl.1454.s1*

## Ethics and consent

We declare that the authors have no conflict of interest to declare. The three experiments reported meet the requirements of informed consent as laid out in European and National ethical guidelines (see art. 19 of Regulation of Establishment of Horizon 2020 No 1291/2013; CNIL for France, NBC for Italy, CEIC for Spain). They received the previous approval of local ethical committees in France (CERES, IRB n° 20163400001072), Italy (Milan Bicocca Ethical Committee, prot. n° 0019845/16) and Spain (Parc de Salut MAR – Clinical Research Ethics Committee, prot. n° 2016/6715/I). The comprehension tests that were used for the experiments are part of the SIGN-HUB assessment tests and are named respectively SYNTRELLSF- *Relative clauses comprehension task in LSF* (Hauser et al. 2019), SYNTRELLIS- *Relative clauses comprehension task in LIS* (Giustolisi et al. 2019), SYNTRELLSC- *Relative clauses comprehension task in LSC* (Zorzi et al. 2019). They are all accessible and usable for assessment on the SIGN-HUB platform under request: *https://www.sign-hub.eu/assessment/welcome-page-assessment*.

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## Competing interests

The authors have no competing interests to declare.

## Author contributions

VA, BG, GZ, JSA, CD and CC contributed to the study conception and design. CD and CC supervised the project and acquired the funding. LSF material, which was used as a baseline for the other sign languages, was prepared by CH, VA and CD and LSF data collection was performed by CH. LIS material preparation and coordination of LIS data collection were performed by BG, RS and CC. LSC material preparation and coordination of LSC data collection were performed by GZ and JSA. Data analysis was performed by CH, BG, and DG. All authors discussed the results. The first draft of the manuscript was written by CH, CD and CC. CH and CD made all the ameliorations suggested by the reviewers. All authors approved the final manuscript.

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## Assessment tools

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