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Solaimani Dahanesari, Ehsan orcid.org/0000-0003-3869-4071, Chondrogianni, Vicky, Bentea, Anamaria et al. (4 more authors) (2025) Bilingualism, Working Memory, and Relative Clause Comprehension in Children. Linguistic Approaches to Bilingualism. ISSN 1879-9272

https://doi.org/10.1075/lab.24037.sol

Bilingualism, working memory, and relative clause comprehension in children

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Bilingualism has sometimes been associated with cognitive boosts, particularly in working memory (WM). However, it remains unclear whether such benefits extend to the comprehension of syntactically complex structures. We investigated this through a gamified character-selection task assessing comprehension of subject-relative clauses and object-relative clauses among monolingual ($n = 31$) and bilingual ($n = 28$) French-speaking children, as well as monolingual ($n = 45$) and bilingual ($n = 43$) German-speaking children aged 3 to 12. We examined whether comprehension correlated with verbal WM, measured through a nonword repetition task, and interference resolution ability, assessed through a Simon task and an analysis of comprehension errors. The results indicated no bilingual advantage: object-relative clauses were more difficult than subject-relative clauses across all groups and languages. While interference-related errors — misinterpreting object-relative clauses as subject-relative clauses more frequently than vice versa — surfaced in all groups, verbal WM correlated with object-relative comprehension only in French. These findings are discussed in relation to current theories of bilingualism and WM in language comprehension.

Keywords: bilingualism, working memory, child language acquisition, relative clauses

1. Introduction

Language acquisition studies have long investigated relative clauses (RCs) such as (1). According to the generative tradition (e.g., Chomsky, 1995), RCs are a subtype of so-called filler-gap dependencies, where successful comprehension requires

https://doi.org/10.1075/lab.24037.sol | Published online: 17 July 2025
Linguistic Approaches to Bilingualism ISSN 1879-9264 | E-ISSN 1879-9272

connecting a displaced noun phrase (NP) or filler – *the bunny* in (1) – from its surface position to its original position or gap, i.e., subject of *pushes* in (1a) and object in (1b), represented by an underscore.

(1) a. *Show me the bunny* [$_{RC}$ *that __ pushes the cat*]. Subject Relative Clause (SRC)

b. *Show me the bunny* [$_{RC}$ *that the cat pushes __*]. Object Relative Clause (ORC)

Due to the non-local nature of the dependency, the filler needs to be stored in working memory (WM) without a clear syntactic function until the verb *pushes* is encountered. In the SRC (1a), there are no intervening NPs between the verb *pushes* and *the bunny*, whereas the subject NP *the cat* in (1b) intervenes between the verb and its direct object, *the bunny*, arguably disrupting successful dependency formation (Gibson, 1998, 2000; Rizzi, 1990, 2004). In fact, previous research has reported that SRCs are easier to process than ORCs and this SRC advantage has been observed cross-linguistically in Indo-European languages such as French (Holmes & O'Regan, 1981), German (Schriefers et al., 1995), and English (Gordon et al., 2001, 2004; Traxler et al., 2002), but also in East-Asian languages like Japanese (Ueno & Garnsey, 2008) and Chinese (Vasishth et al., 2013), although evidence for non-European languages is at times conflicting (Vasishth et al., 2013). The SRC advantage has been reported for both typically developing children and those with language impairments (e.g., Delage & Frauenfelder, 2019; De Villiers et al., 1979) and demonstrated by several studies involving various tasks, such as act-out (De Villiers et al., 1979), picture-selection (Bentea et al., 2016), self-paced reading/listening (Arosio et al., 2012) and sentence repetition (Delage & Frauenfelder, 2019). These studies show that while children understand SRCs by ages 3–4, they can struggle with ORCs until late childhood, with improvement continuing gradually throughout primary school-aged populations (Bentea et al., 2016; Contemori & Marinis, 2014).

Different WM-based explanations have been proposed to account for the SRC advantage. In the present study, we consider two broad views, namely (a) decay-based and (b) interference-based explanations. According to decay-based views (e.g., Dependency Locality Theory; Gibson, 1998, 2000), the WM representation of the filler *the bunny* is attenuated when the filler needs to be stored in WM over a long stretch of words. This approach predicts that the increased difficulty with ORCs is due to the length of the dependency between the filler *the bunny* and the gap, which is greater in (1b) compared to (1a). By contrast, according to interference-based views such as the similarity-based interference perspective (Jäger et al., 2017; Rizzi, 1990, 2004), successful comprehension requires linking the extracted NP *the bunny* to the verb *pushes*, but the intervening NP *the cat* in

(1b) interferes with retrieving *bunny* at the verb from WM. In SRCs like (1a), no intervening NP exists, so no interference is expected, resulting in easier comprehension compared to ORCs like (1b).

While decay-based views attribute the comprehension difficulty of ORCs to the additional information that needs to be retained in WM, interference-based views argue that ORCs require higher levels of inhibition to suppress activation of a distracting NP. Despite these differences, both perspectives agree that the way ORCs and SRCs are processed in WM underlies the observed processing difficulty in ORCs. In the present study, we categorise both accounts as WM-related views but empirically test them by assessing verbal WM storage capacity and the ability to resist interference from other NPs to examine their relationship with SRC and ORC comprehension.

Interestingly, bilingualism, operationalised as the use of two or more languages in daily life (Grosjean & Li, 2013), has been argued to potentially enhance WM in a number of studies (for review, see Monnier et al., 2022). The question arises whether these potentially better WM abilities in bilinguals can impact RC comprehension. While most previous studies have examined possible links between WM and RC comprehension in monolingual and bilingual adults (for review, see Lau & Tanaka, 2021), less is known about how bilingual children's developing WM impacts RC comprehension. Additionally, the effects of bilingualism on cognition may be easier to detect in children than in adults due to their developing cognitive systems (Bialystok et al., 2012). Thus, exploring WM and its connection to RC comprehension in bilingual children can enhance our understanding of how linguistic experience influences developing cognitive and linguistic abilities and their relationship.

Furthermore, whereas the majority of earlier studies have found WM effects in languages such as French, where SRCs and ORCs involve different word orders (Delage & Frauenfelder, 2019), detecting such effects has proven more challenging in verb-final languages like German, which has rich case markings (e.g., Arosio et al., 2012). Therefore, cross-linguistic comparisons between typologically different languages like French and German in WM effects can enrich our understanding of how various types of information are weighted in WM (Kim & Park, 2024). To address these gaps, the present study reports on a gamified experiment that investigated 3-to-12-year-old French- and German-speaking monolingual and bilingual children's comprehension of SRCs and ORCs, while exploring links to WM.

2. Background

Most research on WM has focused on the tripartite model developed by Baddeley and colleagues (Baddeley et al., 2009; Baddeley & Hitch, 1974). This model suggests WM comprises several subsystems: one for the short-term storage of verbal and acoustic information (the phonological loop) and another for visuospatial information, and both are overseen by the central executive, which directs attention and inhibits irrelevant information while updating and monitoring current processing.

The capacity of the phonological loop is typically measured using simple span tasks (Barouillet & Camos, 2007), which assess the ability to temporarily store and recall verbal information. These tasks include nonword repetition and forward digit span tasks, in which children are presented orally with a sequence of stimuli (e.g., nonwords or digits) and are required to repeat them in the same order they were heard. Simple spans increase with age, particularly between two and nine years, and reach adult levels by adolescence (Barouillet & Camos, 2007). In contrast, the capacity of the central executive is assessed using complex span tasks that require both storage and processing. These include backward digit span (Gaulin & Campbell, 1994), listening (Poll et al., 2013) and counting span tasks (Case et al., 1982), where children must not only retain the presented stimuli but also manipulate them – for example, by recalling digits in reverse order – thereby measuring both memory capacity and cognitive processing ability.

The role of WM in syntax has been widely investigated, with evidence suggesting that performance on both simple and complex span tasks correlates with syntactic abilities (e.g., Delage & Frauenfelder, 2019). However, findings remain mixed regarding which specific component of WM is engaged during syntactic processing (Adams & Gathercole, 2000; Bentea et al., 2016; Poll et al., 2013; Sahlén et al., 1999; Willis & Gathercole, 2001). Adams and Gathercole (2000) found that children aged 3 to 5 with higher verbal WM, as assessed through (non)word repetition tasks, produced longer and more structurally complex English sentences compared to those with lower verbal WM. Similarly, Poll et al. (2013) demonstrated that children aged 6 to 13 with stronger WM skills, measured via a listening span task, performed more accurately on a sentence imitation task in English than those with lower WM abilities.

However, studies reporting a correlation between different span tasks and syntactic abilities have also reported mixed results. For example, Arosio et al. (2011) observed that performance on the forward digit span task, but not on the listening span task, predicted offline comprehension of ORCs in nine-year-old Italian children. Bentea et al. (2016) investigated French-speaking children's comprehension of ORCs and also assessed WM abilities using forward and backward digit span tasks. Their findings revealed that children had more difficulties with ORCs such as *Montre-moi la dame que la fille embrasse.* ('Show me the lady that the girl is kissing.') and *Montre-moi celle que la fille embrasse.* ('Show me the one that the girl is kissing.') in which the object fillers (*la dame* 'the lady' and *celle* 'the one') and the intervening subject (*la fille* 'the girl') shared similar morphosyntactic features. Crucially, feature similarity posed less difficulties for children with high forward digit-span scores. This study found no relationship between comprehension accuracy and backward digit-span scores.

The findings by Bentea et al. (2016) underscore the importance of interference in morphosyntactic features as a potential factor contributing to children's difficulty with ORCs. However, interference is not bound to morphosyntactic levels but may also occur at the level of thematic role assignment. Diessel and Tomasello (2005) demonstrated that when four-year-old children listened to SRCs vs. ORCs while viewing reversible images (e.g., a boy chasing a girl vs. a girl chasing a boy), they often selected the distractor image for ORCs (e.g., interpreting 'a boy who the girl is chasing' incorrectly as 'a boy who is chasing the girl'). Similar findings have been reported by Brandt et al. (2016). This suggests that children rely, among others, on canonical word order cues to initially interpret both SRCs and ORCs as SRCs. As a result, they may struggle to suppress interference from a competing SRC interpretation in ORCs. This leads to the misassignment of thematic roles.

While these findings highlight the role of WM in syntactic processing, the nature of the observed WM effects remains difficult to interpret. Simple span tasks, such as nonword repetition, require children to repeat stimuli in the same order in which they were heard, primarily measuring storage rather than the processing capacity of WM. As such, these tasks assess resistance to decay-based forgetting but do not capture how WM processing is engaged in resolving interference. In contrast, complex WM tasks involve both storage and inhibition of irrelevant information. As a result, using complex span scores as measures of WM in syntactic processing can conflate its storage and processing functions, making it difficult to distinguish between decay- and interference-based effects. That is, correlations between syntactic abilities and complex span scores may reflect difficulties either in storing syntactic relations in WM or in manipulating its content to resolve interference.

Importantly, neither decay- nor interference-based explanations specify how different types of information are weighted in WM during RC comprehension. In German, RCs can be ambiguous between an SRC and ORC interpretation, with disambiguating information provided either via subject–verb agreement (2) or case marking (3). In (2), the relative pronoun *die* and the plural definite article *die* in the NP *die Kinder* ('the children') are ambiguous between the nominative and accusative case. In these sentences, it is the agreement morphology of the embedded auxiliary (*hat* vs. *haben*) that indicates a subject (2a) vs. an object (2b) interpretation. By contrast, in (3), it is the case marking on the embedded NP that disambiguates between a SRC or ORC interpretation: the embedded NP *den Clown* in (3a) is marked for accusative, thus triggering a SRC interpretation, while the embedded NP *der Clown* in (3b) is marked for nominative, indicating that the head of the RC, *die Frau* 'the lady', should be interpreted as the object of the embedded verb.

(2) a. *Die Frau, die die Kinde gesehen hat*
The woman, who the children seen have$_{3SG}$
'The woman who has seen the children' SRC (subject–verb agreement)

b. *Die Frau, die die Kinder gesehen haben*
The woman, who the children seen have$_{3PL}$
'The woman who the children have seen' ORC (subject–verb agreement)

(3) a. *Die Frau, die den Clown gesehen hat* SRC (case marking)
The woman, who the$_{ACC}$ clown seen have$_{3SG}$
'The woman who has seen the clown'

b. *Die Frau, die der Clown gesehen hat* ORC (case marking)
The woman, who the$_{NOM}$ clown seen have$_{3SG}$
'The woman who the clown has seen'

Arosio et al. (2012) assessed digit spans and investigated the effects of different disambiguating cues in a character-selection task with seven-year-old German-speaking children. Similar to previous studies, they found that ORCs were more difficult. Arosio et al. (2012) divided the participants into low-, medium-, and high-span groups based on their digit span scores. Low-span children showed poor comprehension accuracy (< 40%) regardless of the type of disambiguation. Medium-span children struggled more with ORCs disambiguated by agreement (2b), achieving less than 45% accuracy, while their accuracy improved to 75% for ORCs disambiguated by case (3b). In contrast, high-span children demonstrated equally high accuracy on both types of ORCs, exceeding 80%. Arosio et al. (2012) concluded that WM is not particularly taxed in German ORCs when case disambiguation is used. This finding aligns with similar results in adults (Friederici et al., 1998), suggesting that case disambiguation may be weighted more strongly in WM than agreement disambiguation.

Interestingly, bilingualism has been linked to improvements in various executive functions, such as WM (Bialystok et al., 2005) and inhibition (Donnelly et al., 2015). Bilinguals keep both languages active in the brain even when only one is being used (for review, see Kroll et al., 2012). Managing competing languages requires resources from WM, and the continual use of these resources could lead to enhanced WM, to achieve more efficient processing (Thorn & Gathercole, 1999).

However, recent meta-analyses cast doubt on the existence of a bilingual advantage, with a subset of studies showing weak evidence or null effects for such an advantage (Donnelly et al., 2019; Paap et al., 2015; see Grundy & Timmer, 2017, for evidence against these meta-analyses). Grundy (2020) argues that these mixed findings reflect the complexity of bilingualism as several key bilingualism-related factors have been often overlooked in past research. For instance, Surrain and Luk (2019) reviewed 186 studies published between 2005–2015 and found that 23% did not report details on L2 proficiency, and 61% did not provide information on L2 use. This lack of information is problematic since several studies have highlighted the role of L2 proficiency, immersion, and use on brain structure and function (e.g., Pliatsikas et al., 2017). Similarly, Valian (2015) noted that young monolingual and bilingual adults performed similarly on a Simon task measuring inhibition, with group differences emerging only in children and older adults. This suggests that the effect of bilingualism on WM and inhibition may not be linear across the lifespan and is more likely to be observed in children than adults.

3. The present study

Against this background, we adopted an individual differences approach to language acquisition (Tomić et al., 2024) and investigated monolingual and bilingual children's comprehension of SRCs and ORCs while exploring their relationship with WM abilities. We administered the same comprehension task in French and German, hypothesising that ORCs would be more challenging due to their greater computational demands compared to SRCs. Overall, the research questions (RQs) were:

RQ1. Is there a difference in comprehension accuracy between monolingual and bilingual children when interpreting RCs in French and German?

RQ2. How do verbal WM, visuospatial WM, and inhibitory control impact the comprehension of French and German RCs by monolingual and bilingual children?

RQ3. Is there a difference in the rates of ORC vs. SRC misinterpretations, as reflected in the number of reversal errors, between monolingual and bilingual children in French and German?

RQ4. How do verbal WM, visuospatial WM, and inhibitory control impact monolingual and bilingual children's rates of reversal errors in French and German RCs?

To examine decay-based effects, we assessed verbal WM using a nonword repetition (NWR) task.[1] If ORC difficulty arises from the longer filler-gap dependency involved in ORCs, we predicted that children with higher verbal WM would perform more accurately on ORCs than those with lower verbal WM. For interference-based effects, we assessed inhibitory control using a Simon task and hypothesised that if ORC difficulty is driven by the need to suppress a competing SRC interpretation, children with stronger inhibitory control would show higher ORC accuracy than those with weaker inhibitory control. While the cognitive mechanisms underlying similarity-based interference remain largely unexplored (Yadav et al., 2022), it is plausible that inhibitory control plays a role in resisting interference from a distracting NP. To provide a more comprehensive view, we also analysed the distribution of comprehension errors in order to determine the extent to which children misinterpret ORCs as SRCs. Following Diessel and Tomasello (2005), we predict a higher rate of reversible errors in ORCs than in SRCs, if interference from a competing interpretation contributes to ORC difficulty.

Regarding the relationship between bilingualism and WM, if there is a bilingual advantage in ORC comprehension, we expect that, after accounting for background variables such as age and language proficiency, bilinguals outperform their monolingual peers in ORC comprehension. By contrast, we do not expect to find a difference between monolinguals and bilinguals, if bilingualism does not lead to improved RC comprehension. To further investigate the seemingly controversial bilingual advantage, we also examined how different WM components might be related to RC comprehension, including measures of verbal and visuospatial WM.

1. An anonymous reviewer noted that the use of non-word repetition is not an ideal proxy for verbal working memory as participants do not need to manipulate the information in short term memory. We note that unlike phonological memory, which involves the passive retention of sounds, nonword repetition tasks require the encoding of unfamiliar phonological sequences (nonwords), their maintenance through subvocal rehearsal, and their accurate reproduction. Because nonwords lack lexical associations, participants must rely on the phonological loop, which is a core component of verbal WM, to temporarily store and rehearse the information. Additionally, as sequences grow longer or more complex, the task also engages executive functions like attention, sequencing, and self-monitoring. Nevertheless, we recognise that nonword repetition may mainly reflect short-term storage, particularly given the high average scores (see Table 1), which suggest minimal simultaneous processing. Our primary reason for including it over a complex span task was to examine decay-based influences on comprehension. Complex span tasks, by contrast, involve both storage and concurrent processing, making them less suited to isolating decay effects. Thus, while we do not take a strong stance on whether nonword repetition tasks measure phonological WM versus short-term memory, we argue that they provide a more valid measure of decay-based forgetting than complex span tasks.

3.1 Participants

Data for this study came from 76 monolingual (mean age 8;1) and 71 bilingual children (mean age 8;0), in line with other studies applying similar age cut-offs for investigating how RCs are interpreted (e.g., Bentea et al., 2016). Participants were recruited in Switzerland (*n* = 57), France (*n* = 31), and Germany (*n* = 59). Children's parents completed the *Quantifying Bilingual Experience* (*Q-BEx*) questionnaire (De Cat et al., 2022), indicating that the children's dominant language was either French or German, while also being exposed to additional languages. Children's dominant language (French for the French group and German for the German group) was the language that they were most proficient in, as assessed by Q-BEx (see below for details). Following Cantone (2022) and Hantman et al. (2023), we defined bilinguals as those children whose parents identified their children's exposure to a second most proficient language since birth (i.e., cumulative exposure) to be more than 20%. There were 31 monolingual French-dominant children residing in France (*n* = 22) and Switzerland (*n* = 9), and 45 German-dominant monolingual children residing in Germany (*n* = 37) and Switzerland (*n* = 8). Among bilingual children (*N* = 71), 28 had French as their dominant language, of whom 14 (50%) were simultaneous bilinguals (they were exposed to two languages from birth), and 43 had German as their dominant language, of whom 28 (65%) were simultaneous bilinguals.

Testing was conducted in children's dominant language (either French or German) in a highly multilingual context. Therefore, the bilingual vs. monolingual classification does not suggest that the so-called monolinguals were not exposed to additional languages. Some monolingual children were exposed to languages other than their dominant language, but their cumulative exposure to these languages was below the cutoff 20%. Similarly, within the bilingual group, some children were also exposed to a third language but their cumulative exposure to this language was less than 20%.

Alongside other background variables, we measured composite scores on the richness of exposure to different languages, which varied based on the frequency with which children engaged in daily activities using different languages (e.g., doing homework, receiving lessons at school, using technology) as well as proficiency in those languages (parents rated how well their children's proficiency was in each language compared to their same age peers).

As shown in Table 1, bilinguals' exposure to their dominant language was less rich compared to their monolingual peers but they had richer exposure to their non-dominant language. Additionally, bilinguals were more proficient in their non-dominant language than monolinguals. This suggests that the bilingual–monolingual distinction in this study was not solely based on differences in the amount of exposure to the dominant language but also took into account language proficiency in and exposure to non-dominant languages. Beyond linguistic variables, we measured verbal WM (NWR), visuospatial WM (Corsi), and inhibition (Simon task; see Section 3.4 for details). All tasks were adapted on tablets to ensure they were suitable for the age range of the children being tested. While no differences in inhibition were found between monolingual and bilingual children in either French or German, a bilingual advantage emerged in NWR across both languages. Additionally, bilingual children outperformed monolinguals on Cosi in French, but not in German.

Table 1. Comparisons of demographic, linguistic, and cognitive background variables between monolinguals and bilinguals

	French dominant				German dominant			
	Bilingual (N=28)	**Monolingual (N=31)**	***p***	***p*-adjusted**	**Bilingual (N=43)**	**Monolingual (N=45)**	***p***	***p*-adjusted**
Sex (at birth)								
Male	12 (43%)	15 (48%)			21 (49%)	25 (56%)		
Female	16 (57%)	16 (52%)			22 (51%)	20 (44%)		
Age (months)								
Mean (SD)	91 (26)	93 (24)	.761	.846	102 (27)	99 (26)	.597	.672
Median [Min, Max]	96 [41 138]	91 [52, 133]			103 [50 138]	104 [41, 138]		
Richness of exposure to dominant language (min 0, max 1)								
Mean (SD)	.576 (.162)	.698 (.130)	**.003**	**.015**	.669 (.148)	.751 (.113)	**.005**	**.011**
Median [Min, Max]	.534 [.295, .886]	.716 [.409, .886]			.682 [.34,1 .864]	.773 [.500, .909]		
Dominant language proficiency (min 0, max 1)								
Mean (SD)	.780 (.233)	.789 (.165)	.866	.866	.826 (.206)	.842 (.218)	.724	.724
Median [Min, Max]	.917 [.250, 1]	.500 [.417, 1]			.833 [.500, 1]	1.000 [.333, 1]		

Table 1. *(continued)*

	French dominant				German dominant			
	Bilingual (*N*=28)	**Monolingual (*N*=31)**	***p***	***p*-adjusted**	**Bilingual (*N*=43)**	**Monolingual (*N*=45)**	***p***	***p*-adjusted**
AoO non-dominant language								
Mean (SD)	12 (18)	40 (22)	**<.001**	**.005**	4 (11)	49 (39)	**<.001**	**.002**
Median [Min, Max]	1 [0, 63]	6 [0, 85]			0 [0, 44]	54 [0, 97]		
Richness of exposure to non-dominant language (min 0, max 1)								
Mean (SD)	.407 (.172)	.311 (.180)	**.041**	.059	.428 (.127)	.312 (.136)	**<.001**	**.002**
Median [Min, Max]	.409 [.045, .841]	.261 [.114, .591]			.432 [.136, .841]	.318 [.114, .659]		
Non-dominant language proficiency (min 0, max 1)								
Mean (SD)	.545 (.218)	.368 (.269)	**.014**	**.023**	.593 (.173)	.393 (.304)	**.002**	**.006**
Median [Min, Max]	.542 [.167, .917]	.333 [.114, .833]			.593 [.250, .917]	.333 [.102, .736]		**NWR**
Mean (SD)	14.80 (1.67)	13.70 (1.30)	**.007**	**.016**	14.50 (1.64)	13.60 (1.30)	**.006**	**.011**
Median [Min, Max]	14.50 [12, 16]	14.50 [13, 16]			14.00 [10, 16]	13.80 [9, 16]		

Table 1. *(continued)*

	French dominant				German dominant			
	Bilingual (*N*=28)	**Monolingual (*N*=31)**	***p***	***p*-adjusted**	**Bilingual (*N*=43)**	**Monolingual (*N*=45)**	***p***	***p*-adjusted**
Corsi								
Mean (SD)	4.86 (1.03)	3.97 (1.45)	**.008**	**.017**	4.63 (1.43)	4.23 (1.33)	.178	.267
Median	5.00	4.22			5	4		
[Min, Max]	[1, 5]	[1, 6]			[2, 6]	[1, 6]		
Inhibition								
Mean (SD)	−.005 (.102)	−.043 (.120)	.194	.242	−.034 (.123)	−.051 (.123)	.519	.667
Median	−.008	−.031			−.009	−.037		
[Min, Max]	[−264, .222]	[−.537, .130]			[−.717, .088]	[−.173, .045]		

Notes. *p*-value adjustment represents p-values derived from independent samples *t*-test corrected for multiple comparisons using the Benjamini-Hochberg method. AoO = Age of Onset; Dominant language refers to French or German, while the non-dominant languages varied among individuals.

3.2 Procedure

Children were tested over the course of two sessions on different days to avoid fatigue, in a quiet environment with an experimenter present to assist them through the tasks. Tests were conducted in either French or German, with children tested in their most proficient language. Alongside the Syntactic Comprehension Task, children also completed the same WM and inhibition tasks.

3.3 Gamified syntactic comprehension task

This task tested comprehension of various syntactic structures via a gamified app on a tablet (iPad). The app was designed for young children and children with linguistic and cognitive impairments, and thus avoided unnecessary visual and verbal details. RC comprehension was assessed on 12 items (6 SRC, 6 ORC), interspersed with 48 fillers of different levels of syntactic complexity.[2] Following a familiarisation phase, the items were randomised. Vocabulary was designed with reference to French/German language norms for words expected for children aged 3–6 years (MacArthur-Bates CDI2).

RC comprehension was tested in a character-selection task in which children heard a restrictive SRC or ORC and then touched the character identified. This meant choosing only one among three characters that were involved in the same action (Figure 1). Indeed, a discourse function of RCs is to effectively single out a character (Solaimani & Marefat, 2024), e.g., a particular bunny among more than one (*the bunny that …*). All items maintained the same format, as follows:

a. Familiarisation with the main characters in the target structure (e.g., *I see two rabbits and a cat*);
b. Aural presentation of the test item while looking at the image on the screen;
c. Each image presented three response options. The characters on the left and right represented the RC filler, either as the agent or patient of the depicted action. One character matched the accurate agent-patient role, while the other followed a reversible theta-role. The middle character, always the embedded NP's referent, was never associated with the target answer. We refer to this option as the 'oddball'.

2. This study was part of a larger project that also investigated other structures, which served as fillers for the RCs in this study. The target structures of the fillers were simple ($n=6$) and complement clauses ($n=6$), active ($n=6$) and passive ($n=6$) voice structures, subject ($n=6$) and object ($n=6$) interrogatives, and sentences involving direct ($n=6$) and indirect ($n=6$) reported speech.

d. once the child selected a response, a motivating attention-grabber appeared on the screen (e.g., a star).

Example (3) illustrates a test item in both French and German.

Figure 1. Example of image associated with a test item

(4) a. *Je vois deux lapins et un chat.* (French) | *Ich sehe zwei Hasen und eine Katze.* (German)
'I see two rabbits and a cat.'

b. *Montre-moi le lapin qui pousse le chat.* SRC, French
show-me the.$_{\text{M.SG}}$ rabbit that pushes the.$_{\text{M.SG}}$ cat.
Zeig mir den Hasen, der die SRC, German
show-me the.$_{\text{ACC.M.SG}}$ rabbit who$_{\text{NOM.M.SG}}$ the.$_{\text{NOM/ACC.F.SG}}$
Katze schiebt.
cat pushes.
'Show me the rabbit that is pushing the cat'

c. *Montre-moi le lapin que le chat pousse.* ORC, French
show-me the.$_{\text{M.SG}}$ rabbit that the.$_{\text{M.SG}}$ cat pushes.
Zeig mir den Hasen, den die ORC, German
show-me the.$_{\text{ACC.M.SG}}$ rabbit who$_{\text{ACC.M.SG}}$ the.$_{\text{NOM/ACC.F.SG}}$
Katze schiebt.
cat pushes.
'Show me the rabbit that the cat is pushing'

For all items, the critical sentence appeared in the format 'Show me + *Filler* + *RC*' and included definite NPs with animal referents. The first NP ('the rabbit') was the filler, while the second NP ('the cat') functioned as either the subject or object within the RC. In the French items, disambiguation towards an ORC vs. SRC interpretation occurred via word order cues, i.e., *le chat* 'the cat' followed the verb *pousse* 'chases' in SRCs (4b), while it preceded the verb *pousse* 'chases' in ORCs (4c). By contrast, in the German items, disambiguation occurred via case-marking on the relative pronoun: *der* in SRCs (4b), indicating that the preceding filler should be interpreted as subject; *den* in ORCs, pointing to an object interpretation of the filler *den Hasen*.

3.4 Cognitive and linguistic variables

3.4.1 *Verbal WM: Nonword repetition*

Verbal WM was assessed through a NWR task from the LITMUS test battery (Hamdani et al., 2024). Participants were required to repeat 16 nonwords (that do not exist in any language), which varied in syllable length from 2 to 5. Verbal WM was calculated as the total number of correctly repeated nonwords (maximum score: 16). As discussed in Footnote 1, the NWR task provides a measure of ability to resist decay-based forgetting.

3.4.2 *Visuospatial WM: Corsi*

To assess visuospatial WM, an adapted version of the Frog Matrices Corsi Blocks Task was administered (Morales et al., 2013), which required children to recall placements of a frog as it jumped from one cell to another within 3×3 matrices (see Figure 2). The number of jumps increased per trial to assess visuospatial WM capacity. Children recalled the sequential order of jumps in a reverse order, and visuospatial WM was calculated as the maximum number of correctly recalled locations in the reverse order of appearance. For example, if a child correctly recalled 3 locations, but not 4, their visuospatial span was scored 3.

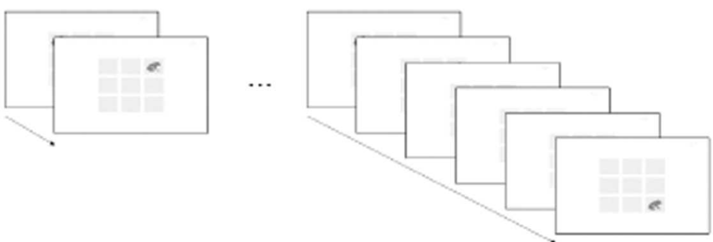

Figure 2. Corsi block test assessing visuospatial working memory

3.4.3 *Inhibition: Simon task*

Finally, we adapted the Simon task (Simon, 1969) from De Cat et al. (2018) for tablet use to assess inhibition. Children sorted stimuli presented on either the right or left upper part of the screen based on colour by clicking on the blue button on the bottom left or the red button on the bottom right part of the screen. Half of the stimuli involved congruent colours, where the stimuli were located above the button in the same color, while the other half had incongruent colours, where the stimuli were located on the opposite side of the corresponding button. The so-called Simon effect was calculated as the mean difference in response times between congruent and incongruent trials, with larger values indicating higher inhibitory control.

3.4.4 *Q-BEx*

This study used the parental questionnaire Q-BEx (De Cat et al., 2022) to collect data on children's language experiences. Q-BEx comprises a series of modules to collect biographic information and assess length and richness of exposure to additional languages, as well as proficiency in these languages. In this study, we focused on data from 'background information', 'language exposure and use', 'proficiency', and 'richness' modules.

3.5 Data analysis

For statistical analysis, separate generalised linear mixed-effects models were created in R (R Core Team, 2020) for each language (French, German), with a maximal random effects structure (Barr et al., 2013). Models were fitted using the lme4 package (Bates et al., 2015) with a logit link function. If a model failed to converge, we first removed the random slopes for items, followed by the random slopes for participants if necessary. If convergence issues persisted, we removed both random slopes. If the model still failed to converge, we applied the same stepwise procedure to the random intercepts for participants and items.

For the first set of models, which assessed RQ1 and RQ2, the dependent variable was response accuracy (accurate vs. inaccurate). For the second set of models, which assessed RQ3 and RQ4, the dependent variable was error type (oddball vs. reversed), and these models included only trials with an erroneous response. The fixed effects included sum-coded (+ .5, − .5) effects of *structure* (SRC, ORC), *group* (monolingual, bilingual), and their interaction; *chronological age*, *verbal WM* (NWR), *visuospatial WM* (Corsi), *inhibition* (Simon), and *proficiency* in the dominant language were scaled and entered as covariates. We did not include any measures of the non-dominant language in our statistical models, such as the non-dominant language proficiency, as this was never the language of the test assessing RC comprehension.[3]

3. Models for NWR, Corsi, and inhibition were fitted separately to avoid issues related to multicollinearity and overparameterisation which may mask the effects of interest. Nevertheless, multicollinearity was checked after each model by inspecting the variance inflation factor (VIF) associated with each model term (VIFs in all models < 5).

Initially, we created a base model to examine the interaction between *structure* and *group* while also incorporating the interaction between *chronological age* and *structure* to account for age-related developmental changes in ORC and SRC accuracy. In addition, *proficiency* was added to the model formula to account for differences in dominant language proficiency (fixed effects formula for the base model: *group*structure* + *age*structure* + *proficiency*). This allowed us to assess RQ1, namely to what extent monolingual and bilingual children interpret SRCs. vs. ORCs differently, while accounting for age and proficiency differences. In the next step, we created another (set of) model(s) to include the 3-way interaction between *structure*, *group*, and different WM-related measurements (NWR, Corsi, inhibition). This allowed us to examine whether different WM-related measurements correlate with monolingual and bilingual accuracy on SRCs vs. ORCs, therefore addressing RQ2 (fixed effects formula in R: base model + *group*structure*WM*).

Finally, to assess RQ3 and RQ4, we focused on the distribution of errors and created parallel sets of models as above on *error type* (Oddball – when the middle character was chosen – and Reversible – when the referent of the RC filler was mapped onto the wrong theta-role) to assess how potential SRC vs. ORC misinterpretations were affected by WM-related variables. If by-group and by-structure interactions were significant, we created additional models on monolingual and bilingual data separately to locate the source of these interactions (for full results on the statistical models, see the OSF link).[4]

4. Results

Initially, we focused on accuracy to assess RQ1 and RQ2, and subsequently, we analysed error patterns to assess RQ3 and RQ4. Figure 3 shows accuracy for monolinguals and bilinguals by RC type and language group, while Figure 4 provides a more detailed breakdown of error type.

4. https://osf.io/msf5x/?view_only=f878ce4a500d435db13853b1d915fa45

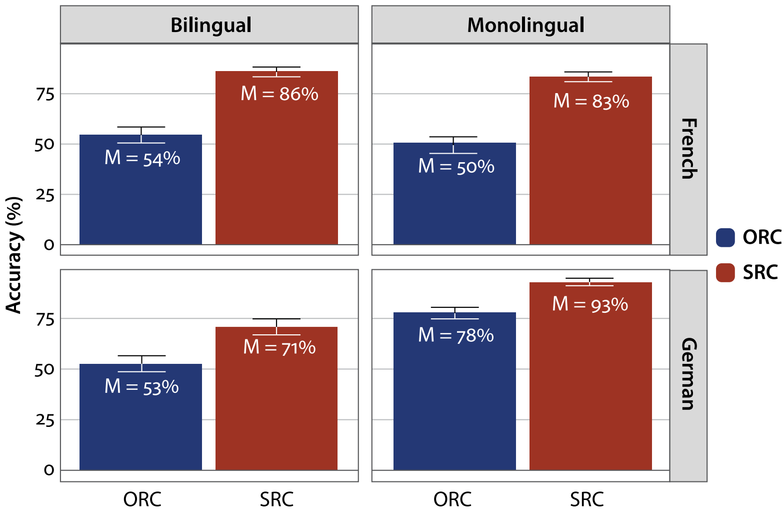

Figure 3. Bilingual and monolingual children's mean comprehension accuracy and 95% confidence intervals on SRCs and ORCs

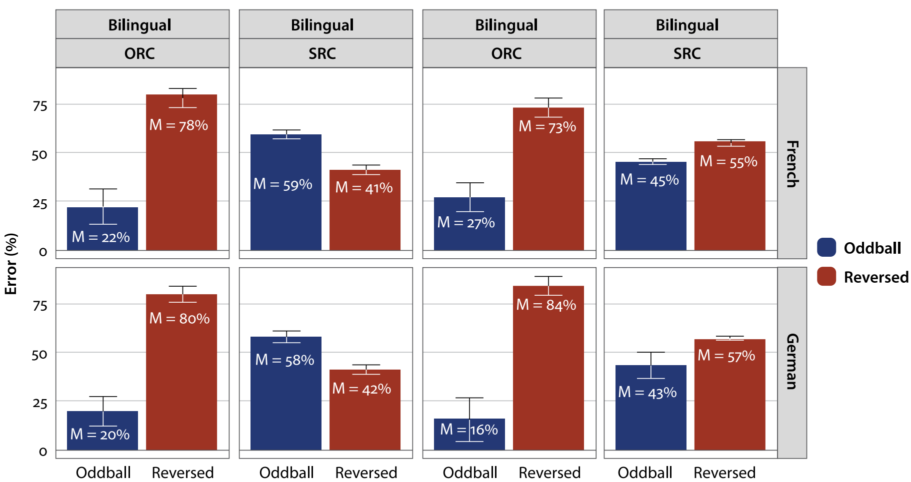

Figure 4. Monolingual and bilingual children's mean error rates and 95% confidence intervals on SRCs and ORCs based on error type (oddball, reversed)

4.1 Monolingual vs. bilingual accuracy on SRCs vs. ORCs (RQ1 & RQ2)

Table 2 presents the results of the models for RQ1 and RQ2. For both French and German, accuracy was higher among older and more proficient children. Accuracy on ORCs was significantly lower than on SRCs, reflecting the expected SRC-ORC asymmetry. In French, there was no significant difference between monolingual and bilingual children, while in German, bilinguals performed significantly worse. The non-significant interaction between *structure* and *group* in German suggests that the accuracy advantage of monolinguals was similar for both SRCs and ORCs.

Table 2. Results of statistical analysis for RQ1 and RQ2 (accuracy)

	French				German			
	Estimate	***SE***	***z***	***p***	**Estimate**	***SE***	***z***	***p***
Intercept	2.983	1.347	2.215	**.027**	3.693	.763	4.839	**<.001**
Structure (ORC vs. SRC)	−5.737	2.676	−2.144	**.032**	−3.883	.766	−5.067	**<.001**
Group (bilingual vs. monolingual)	−.450	.972	−.463	.643	−3.644	1.276	−2.855	**.004**
Age	.710	.120	5.917	**<.001**	.434	.155	2.818	**.005**
Proficiency	1.054	.401	2.626	**.009**	1.078	.436	2.472	**.013**
Structure × Group	1.340	1.811	.740	.459	.728	.891	.818	.414
Structure × Age	−.178	.884	−.202	.840	−.158	.419	−.378	.706
NWR	.295	.310	.953	.341	−1.437	1.143	−1.257	.209
Structure × NWR	1.441	.389	3.705	**<.001**	−3.049	1.865	−1.635	.102
Group × NWR	−.142	.622	−.229	.819	1.397	2.112	.661	.508
Structure × Group × NWR	−.174	.750	−.232	.817	1.994	3.667	.544	.587
Corsi	.640	.266	2.406	**.016**	−.745	.884	−.843	.399
Structure × Corsi	.752	1.042	.721	.471	−.239	1.142	−.210	.834
Group × Corsi	−1.058	1.186	−.892	.372	−2.835	1.738	−1.631	.103
Structure × Group × Corsi	3.829	2.152	1.779	.075	.525	2.351	.223	.823
Inhibition	−.004	.506	−.007	.994	−.457	1.063	−.430	.667
Structure × Inhibition	.094	.970	.097	.923	−.188	1.245	−.151	.880
Group × Inhibition	−1.488	1.054	−1.411	.158	.733	2.100	.349	.727
Structure × Group × Inhibition	.264	1.958	.135	.893	−.495	2.491	−.199	.842

Regarding WM-related measures (RQ2), the only significant effects were for visuospatial working memory (Corsi) and the interaction between *structure* and

NWR in French. Specifically, higher Corsi scores were associated with greater accuracy in French. As for the interaction between Structure and NWR scores in French, while SRC accuracy was at ceiling and showed no significant correlation with NWR scores (Estimate = .401, *SE* = 1.103, *z* = −0.371, *p* = .710), higher NWR scores were associated with significantly improved ORC accuracy (Estimate = .902, *SE* = .321, *z* = 2.811, *p* = .005). This relationship is visualised in Figure 5.

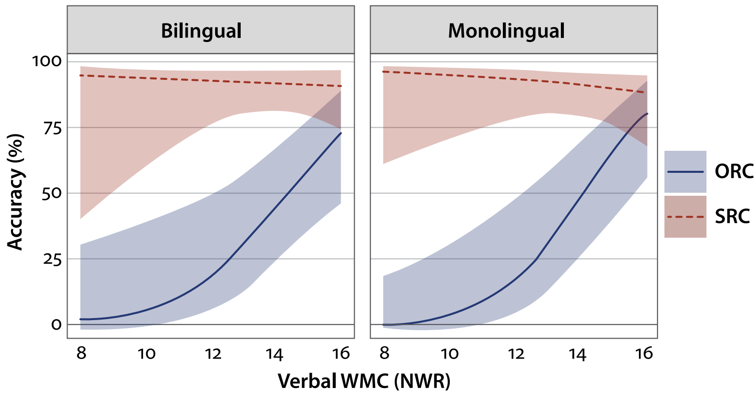

Figure 5. Model predictions for the relationship between NWR scores and SRC vs. ORC accuracy in French

4.2 Reversal errors for monolingual vs. bilingual children on SRCs vs. ORCs (RQ3 & RQ4)

Table 3 presents the results of the statistical analysis for RQ3 and RQ4. For both groups, higher proficiency was associated with lower rates of reversal errors. Additionally, reversal errors occurred significantly more frequently in ORCs than in SRCs. None of the effects related to WM were significant, however, indicating that reversal errors did not correlate with NWR, Corsi, or inhibition scores.

In summary, ORC accuracy was lower than SRC accuracy in both groups. However, while verbal WM correlated with ORCs in French, there was no relationship between NWR, Corsi, or inhibition tasks, and ORCs in German. Regarding error patterns, more reversal errors were found in ORCs than SRCs across groups and languages, but error type did not correlate with any of the WM-related measures tested. Finally, while no monolingual-bilingual differences were found in French, bilinguals performed worse than monolinguals on both SRC and ORC accuracy in German. These findings were obtained after controlling for potential differences in age and proficiency in the dominant language.

Table 3. Results of statistical analysis for RQ3 and RQ4 (error pattern)

	French				German			
	Estimate	***SE***	***z***	***p***	**Estimate**	***SE***	***z***	***p***
Intercept	.840	.417	2.014	**.044**	.877	.302	2.903	**.004**
Structure (ORC vs. SRC)	2.130	.923	2.309	**.021**	2.770	.883	3.137	**.002**
Group (bilingual vs. monolingual)	−.682	.602	−1.133	.257	−.702	.744	−.944	.345
Age	.108	.523	.206	.837	−.134	.467	.287	.774
Proficiency	−.901	.402	−2.241	**.025**	−1.024	.499	−2.052	**.040**
Structure × Group	.963	1.120	.860	.390	1.019	1.388	.734	.463
Structure × Age	−.837	.645	−1.299	.194	−.098	.065	1.500	.134
NWR	−.650	.740	−.878	.380	.290	.590	.492	.623
Structure × NWR	.797	.575	1.386	.165	.994	1.167	.852	.394
Group × NWR	−.478	.310	−1.542	.123	1.634	1.184	1.379	.168
Structure × Group × NWR	.293	.217	1.350	.177	.339	.217	.063	.950
Corsi	−.656	.710	−.924	.355	−.271	.533	−.007	.994
Structure × Corsi	.784	.721	1.087	.277	.515	.706	.729	.466
Group × Corsi	−.358	.294	−1.218	.223	.725	.661	1.097	.273
Structure × Group × Corsi	.908	.571	1.590	.112	−.535	.332	−1.611	.107
Inhibition	.290	.590	.492	.623	−.285	.269	−1.059	.289
Structure × Inhibition	.994	1.167	.852	.394	.906	.540	1.678	.093
Group × Inhibition	1.634	1.184	1.379	.168	−.838	.474	−1.767	.077
Structure × Group × Inhibition	−3.667	2.346	−1.563	.118	.782	.949	.824	.410

5. Discussion

This study investigated SRC vs. ORC comprehension accuracy in French and German among monolingual and bilingual children aged 3 to 12. Specifically, it explored the relationship between RC accuracy, verbal and visuospatial WM, and inhibition. Precisely, this analysis aimed to examine the relative contributions of decay- and interference-based factors in the role of WM in SRC and ORC comprehension.

We predicted that ORC comprehension would be lower than SRC comprehension in both French and German. This follows from previous studies demonstrating that compared to SRCs, ORCs are associated with higher processing costs and lead to stronger misinterpretation of the thematic roles involved. Specifically, we predicted that if WM effects vary based on the nature of disambiguating information (word order in French vs. case marking in German), WM should be solicited more strongly in French compared to German, in line with previous studies showing that WM is not particularly taxed when disambiguation towards an ORC interpretation occurs via case, as in German (Arosio et al., 2012). Regarding potential monolingual-bilingual differences, we predicted that if bilingualism leads to improved RC comprehension due to enhanced WM abilities, bilingual children should perform better on ORCs than their monolingual peers (i.e., bilinguals should show a smaller ORC disadvantage).

5.1 Comprehension accuracy (RQ1 & RQ2)

The results showed that in both French and German, comprehension accuracy was lower in ORCs than in SRCs, consistent with previous studies indicating that ORCs are more difficult. Additionally, accuracy improved with age and proficiency in both languages, with older and more proficient children performing better than their younger and less proficient peers. Despite these similarities, we argue that the results do not necessarily imply that children relied on the same cognitive and linguistic resources to comprehend ORCs and SRCs in both languages. This is because NWR and Corsi effects on ORCs were found only in French and not in German, while reversal errors were similarly more likely in ORCs than in SRCs in both languages, indicating that comparable levels of inhibition were involved in resisting an initially preferred SRC interpretation in both French and German ORCs. In addition, we did not find a bilingual advantage in accuracy in either French or German, despite bilinguals having (descriptively) higher verbal WM, visuospatial WM, and inhibitory control (see Table 1); in fact, bilingual children performed worse on both ORCs and SRCs in German even after controlling for age and proficiency differences, thus casting doubt on the hypothesis that bilingualism boosts RC comprehension.

Focusing specifically on French, the results showed that although there was an advantage for SRCs, children with higher NWR scores demonstrated greater comprehension accuracy on ORCs compared to those with lower NWR scores. This is consistent with the hypothesis that children with high verbal WM are less affected by the relatively longer filler-gap dependency in ORCs than their peers with low verbal WM. We found no difference in accuracy between monolingual and bilingual children in French, suggesting that ORCs were equally difficult for both groups, with verbal WM correlating similarly strongly with ORC comprehension. While higher visuospatial WM was associated with improved accuracy on both SRCs and ORCs, we did not find any relationship between accuracy and our inhibitory control measure obtained from the adapted Simon task. We remain cautious about interpreting the lack of interaction between inhibitory control and comprehension accuracy, however, since our study did not manipulate the similarity between the displaced NP and the intervening NP in the same way as studies reporting interference effects (e.g., Bentea et al., 2016). Thus, while no association was found between our specific measure of inhibitory control and ORC comprehension, we do not claim that the intervening NP in ORCs did not create any interference effects (Rizzi, 2004; Van Dyke & Johns, 2012).

Additionally, the interaction between ORC accuracy and NWR scores was found only in French but not in German, consistent with previous studies reporting no WM effect in German RCs disambiguated by case marking. One possible explanation for the lack of verbal WM effects in German ORCs is that disambiguation occurred early in the sentence, on the relative pronoun (der in SRCs, den in ORCs), allowing listeners to identify RC type midway through processing. In contrast, French RCs were only disambiguated by word order, requiring listeners to process a longer structure before encountering the verb and determining whether the clause was an SRC or ORC. As a result, revising an initially preferred SRC interpretation likely imposed a lower load on the underlying verbal WM in German than in French, as less information has to be retained in WM before reaching disambiguating cues.

In fact, bilinguals in German had lower SRC accuracy (71%) than bilinguals in French (86%), whereas monolinguals in German had higher accuracy on ORCs (78%) than their French counterparts (50%). This is consistent with the view that it may be easier to revise an initial SRC interpretation when less information is retained in WM before reaching the disambiguation cue. The fact that German bilinguals also struggled with SRCs suggests that they are likely not using case information to the same extent as monolinguals. However, this raises the question of why bilingual children in German have lower accuracy on both SRCs (93% vs. 83%) and ORCs (78% vs. 50%) compared to their monolingual peers. This is likely due to less efficient processing of morphological information on the relative pronoun, which improves with proficiency and rich input exposure, which was lower among the bilingual German-dominant children compared to their monolingual counterparts.

5.2 Reversal errors (RQ3 & RQ4)

The distribution of errors revealed that children made more reversal errors in ORCs than in SRCs, suggesting that they were more likely to misinterpret ORCs as SRCs than vice versa. Reversal errors were similarly more likely in ORCs than in SRCs in both languages, demonstrating that children rely on a default subject-first interpretation when processing filler-gap dependencies (Atkinson et al., 2018). This also suggests that comparable levels of inhibition were involved in resisting a competing interpretation in both French and German ORCs vs. SRCs. However, reversible errors did not correlate with our measure of verbal WM, visuospatial WM, and inhibitory control, suggesting that our WM-related measures likely did not tap into interference at the level of thematic role interpretation.

The lower accuracy on German ORCs, despite lower verbal WM demands in German RCs (disambiguated via case) compared to French (disambiguated via word order), suggests that verbal and visuospatial WM were not the primary factor influencing German RC comprehension. Instead, German-dominant children struggled particularly with revising an initial SRC interpretation, as indicated by the higher number of reversal errors in German than in French ORCs vs. SRCs (German: 67% vs. 33%; French: 63% vs. 37%). Thus, children perceived German ORCs as more difficult than German SRCs, at least partly due to initial misanalysis, even though case marking in German reduced verbal WM costs relative to word order-based disambiguation in French. This suggests that verbal WM alone does not fully account for the observed SRC advantage in both languages. Instead, WM must work in conjunction with inhibition to update ongoing processing by resisting interference from a competing interpretation. In other words, the relative involvement of verbal WM and inhibition in RC comprehension does not appear to be a universal processing feature but likely varies across languages.

Finally, we note that the non-dominant languages of the children tested were highly varied. Therefore, it is unlikely that the findings for children with either French or German as their dominant language represent a systematic pattern of cross-linguistic influence. However, the discrepancy in WM effects between German and French relative clauses highlights the importance of cross-linguistic evidence when drawing conclusions about the cognitive underpinnings of language comprehension. For example, Delage et al. (2021) demonstrated that both children with Developmental Language Disorder (DLD) and children with typical development (TD) showed improvement in producing French ORCs after a WM training program. Although our study did not directly test production, it remains unclear to what extent such improvements would transfer to other languages, like German, which does not exhibit a similar word order in subordinate clauses.

6. Conclusion

This study found that the presence or absence of verbal WM and inhibition effects on RC comprehension among children varies based on their previous linguistic experience and age. Specifically, in French, where RCs are disambiguated towards an SRC vs. ORC interpretation using word order cues, comprehension accuracy is more strongly associated with verbal WM, whereas in German, where RCs are disambiguated using case, children primarily rely on canonicity cues, to interpret SRCs and ORCs, rather than depending heavily on verbal WM.

Additionally, we did not find any evidence that bilingualism results in better ORC comprehension. However, the sample size for the French-dominant children ($n = 58$), where WM effects were found, was smaller than the sample size for the German-dominant children ($n = 88$), where WM effects were not observed. It is thus necessary to conduct higher-powered replications to further examine the cross-linguistic differences and the impact of bilingualism on syntactic comprehension in young children. This is especially important as the German children in this study were overall about 9 months older than the French children. Therefore, while we accounted for age effects in our statistical analysis, we remain cautious in interpreting the observed cross-linguistic asymmetry and emphasise that more research is needed with more balanced linguistic groups.

Funding

This study was supported by the Swiss National Science Foundation (SNSF) awarded to Stephanie Durrleman (grant PR00P1_193104/1).
Open Access publication of this article was funded through a Transformative Agreement with University of York.

Data availability

Data, code to reproduce the analyses are available under: https://osf.io/msf5x/

Acknowledgements

We warmly thank all the families and children who participated in this study. Thanks also to our collaborators and students for their investment in both material creation and data collection.

Conflict of Interest Statement

The authors declare that they have no conflict of interest pertaining to the research, authorship, and/or publication of this article.

Compliance with Ethical Standards and informed consent

This study was approved by the Swiss Association of Research Ethics Committees *Swissethics* (Project ID-2022-00878) and is in accordance with the 1964 Helsinki declaration and its later amendments. All parents provided informed consent for their child's participation prior to their inclusion in the study.

Authors' contributions

Ehsan SOLAIMANI: conceptualisation, formal analysis, visualisation, data curation, writing – original draft, writing – review and editing. Pauline WOLFER: investigation, methodology, data curation, resources, writing – review and editing. Franziska BAUMEISTER: investigation, methodology, data curation, resources, writing – review and editing. Stephanie DURRLEMAN: conceptualisation, funding acquisition, methodology, supervision, project administration, resources, writing – review and editing. Vicky CHONDROGIANNI: methodology, resources, writing – review and editing. Anamaria BENTEA: methodology, resources, writing – review and editing. Hélène DELAGE: resources, writing – review and editing. All authors reviewed and approved the manuscript for publication.

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Publication history

Date received: 10 June 2024
Date accepted: 2 June 2025
Published online: 17 July 2025