Tracking the Role of Prosody in Sentence Processing: Evidence from Children Speaking English as an Additional Language (EAL)

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1. Introduction

The Late Closure Principle (Frazier, 1979) predicts that, when encountering globally ambiguous sentences with a PP attachment ambiguity such as (1) below, the parser should show preference for high attachment (HA). This has indeed been confirmed in past research with adults showing HA preference and participants therefore interpreting *the binoculars* as an instrument used by the subject, rather than as a modifier to *the man* (Clifton et al., 1991; Frazier, 1979; Rayner et al., 1983).

(1) a. [The woman][saw [the man]][with the binoculars] High Attachment
b. [The woman][saw [the man][with the binoculars]] Low Attachment

Among monolingual speakers of English, these HA preferences are even higher in children compared to adults (López Lugo, 2024). This default parsing preference can be heavily influenced by lexical semantics, such as verb bias, which has been found to be integrated during language processing by both adults (Snedeker & Trueswell, 2004) and children (Kidd & Bavin, 2005; Snedeker & Trueswell, 2004). Syntactic and lexical biases are particularly robust in children, who have been found to ignore additional top-down cues in their presence, such as information in the visual context (Anderson et al., 2011; Kidd et al., 2011; Yacovone et al., 2021). Prosody, however, is an additional cue that children have been found to integrate in spoken sentence processing, though this integration can be delayed in children compared to adults (Snedeker & Yuan, 2008).

Attachment preferences in global ambiguities remain less well-understood among bilingual children, and especially children speaking English as an

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Additional Language (EAL) in the UK education context. EAL research has focused primarily on the comprehension of written passages, vocabulary and grammar development, and overall literacy acquisition (Murphy, 2017). To the best of our knowledge, the modulation of default HA preferences by semantics and prosody remains unexplored among EAL children. According to the Shallow Structure Hypothesis (Clahsen & Felser, 2006a, 2006b), which proposes that L2 speakers rely relatively more on lexical, semantic, and discourse cues than on detailed syntactic representations during sentence processing and reanalysis, we may expect EAL children to be more sensitive to verb semantics than prosody in the context of cue competition. Monolingual children, on the contrary, may show deterministic adult-like HA preferences and, therefore, reduced sensitivity to additional cues.

This paper presents a visual world paradigm (VWP) eye-tracking experiment, in which we tap into the priority ranking of syntax, semantics, and prosody in the processing of spoken sentences among monolingual children and investigate whether this ranking differs in EAL children. We operationalise this research question by focusing on PP attachment ambiguities such as (1) and investigate children's attachment preferences in their responses and eye movements.

2. Participants

Our sample consists of 64 UK Year 5 primary school pupils (age *M* = 9;11, *Mdn* = 9;11, *SD* = 0;4, range = 9;3 – 10;8), 37 of whom are EAL pupils (18 girls and 19 boys) and 27 monolingual pupils (14 girls and 13 boys). We collected language background, exposure, and use data among EAL pupils using the Q-BEx questionnaire (De Cat et al., 2023). The majority of EAL pupils were first exposed to English at home (*n* = 26; 70.3%), with a further 10 at pre-school (27.0%) and 1 at school (2.7%). Our sample predominantly consists of early bilinguals (*M* = 1;7, *Mdn* = 0;6, *SD* = 1;10, range = 0;0 – 6;3), with 20 EAL pupils reporting an age of onset before the age of 2 years. Eleven pupils (29.7%) were born outside the UK (*M* = 2;8, *Mdn* = 3;0, *SD* = 1;10, range = 0;0 – 6;3). On average and across contexts, EAL children reported being exposed to and using English approximately two thirds of the time (Exposure (%): *M* = 62.67, *Mdn* = 61.82, *SD* = 12.9, range = 33.42 – 88.07; Use (%): *M* = 66.22, *Mdn* = 65.39, *SD* = 13.83, range = 35.96 – 94.24).

Of the 37 EAL pupils in our sample, 32 (86.5%) reported speaking one home language in addition to English, whereas 5 pupils (13.5%) reported two home languages. In total, we recorded 20 unique first home language backgrounds and 5 unique second home language backgrounds (with German, French, and Spanish appearing in both categories). The most prevalent home languages in our sample were Polish (*n* = 6), Chinese (*n* = 3), French (*n* = 3), and German (*n* = 3).

Additionally, we tested children's receptive vocabulary (BPVS-3; Dunne et al., 2009), receptive grammar (TROG-2; Bishop, 2003), and receptive prosody (PEPS-C 2015 Version; Peppé & McCann, 2003; Peppé 2015). In Table 1, we provide descriptive statistics of performance in these tests for each group, as well as a group comparison and note that no significant difference emerged between the two groups in any of the tests. For BPVS-3 and TROG-2, we report standard scores, whereas for PEPS-C, which is not standardised, we report raw percentage-correct scores. Therefore, note that the scores are on different scales, as a standard score of 100 indicates age-appropriate performance, while percentage-correct scores range from 0 to 100.

Table 1. Children's performance in measures of language abilities and comparison by group

	Monolinguals			EAL			
	M	Mdn	SD	M	Mdn	SD	Welch's t
BPVS-3	101.9	102	13.3	101.2	102	12.4	$p = .853$
TROG-2	105.8	109	10.5	103.6	103	11.5	$p = .431$
PEPS-C Receptive	86.9	89.3	11.1	90.2	93.8	8.2	$p = .196$

3. Experimental Materials

Participants listened to sentences such as (2) below featuring a global PP-attachment ambiguity headed by *with*.

(2) a. [The bear][tickled [the penguin]][with the leaf] High Attachment
b. [The bear][tickled [the penguin][with the leaf]] Low Attachment

Our stimuli followed a 2 × 2 factorial design, manipulating verb bias (equi-biased vs. instrument-biased verbs) and prosodic structure (modifier vs. instrument prosody), presented in Table 2. We used five equi-biased verbs, i.e. verbs equally likely to prompt modifier and instrument interpretations, and five instrument-biased verbs, selected based on prior work (Kidd & Bavin, 2005; Ryskin et al., 2017; Snedeker & Trueswell, 2004). Prosodic structure was cued by placing a prosodic boundary either after the verb to signal a LA/modifier reading or before the PP to signal a HA/instrument reading. We indicate the location of prosodic boundaries with a | in Table 2. Each prosodic boundary featured a H* pitch accent followed by a L-L% boundary tone, and pre-boundary lengthening. Recordings were made by a female trained phonetician and native speaker of British English at the Phonetics Laboratory, University of Cambridge. Forty critical items were constructed in total, distributed across four conditions and presented in two counterbalanced lists. Additionally, forty-four filler items were presented to distract from the aim of the experiment.

Table 2. Manipulations in the experimental design

		Verb Bias	
		Equi-biased Verb	**Instrument-biased Verb**
Prosody	**Modifier Prosody**	The bear spotted | the penguin with the glasses	The bear tickled | the penguin with the leaf
	Instrument Prosody	The bear spotted the penguin | with the glasses	The bear tickled the penguin | with the leaf

The visual scene consisted of four full-colour images, and a fixation cross at the centre of the screen (see Figure 1). In each scene, the agent animal (e.g., *the bear* in Figure 1) appeared in two images facing the target animal (e.g., *the penguin*) and in two images facing a distractor (e.g., a *turtle*). Importantly, every image included two candidate objects —one held by the agent, and one held by the other animal— to license both the instrument (HA) and modifier (LA) interpretations while keeping the display visually balanced. The stimuli were adapted from Van Rij et al. (2016), ensuring no change to existing pictures was visually conspicuous.

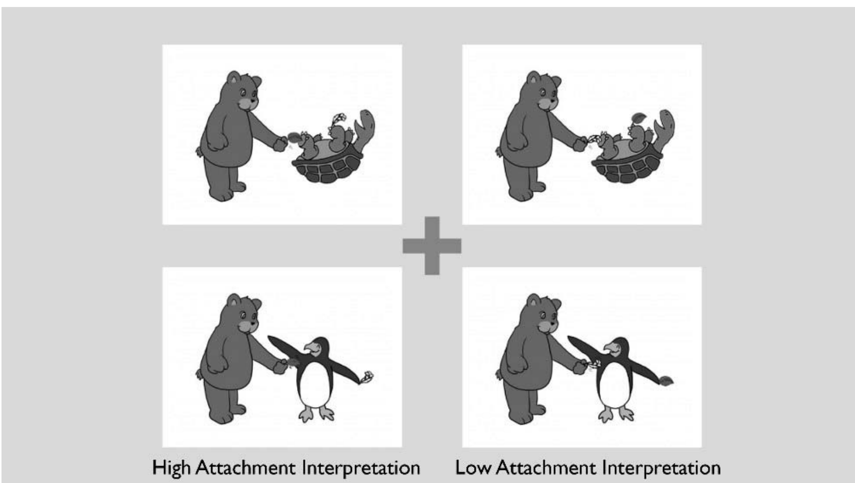

Figure 1. Visual scene example for critical items (annotated)

4. Apparatus and Procedure

All children were tested individually in a quiet room at the school they attended. Right-eye movements were recorded with an SR Research EyeLink Portable Duo eye-tracker in remote, head free-to-move mode sampling at 500 Hz. Visual stimuli were displayed on an ASUS laptop. The experiment consisted of one practice block and three experimental blocks. Each trial of the experiment started with a drift check. The visual scene was then presented for 1000ms to allow participants a preview of the images. The spoken sentence was then presented, after which the fixation cross was replaced by a question mark, prompting the participants to press one of four buttons corresponding to the images on the screen on a button box.

5. Data Analysis
5.1. Response Data

All analyses were conducted in *R* (R Core Team, 2024). To analyse the response data, we fit logistic mixed-effects models using binomial *glmer*s (*lme4* package, Bates et al., 2015). Responses were coded 0 for LA responses and 1 for HA responses. Trials in which participants failed to respond were excluded from the analysis. This affected 0.29% of trials.

First, we conducted a set of models testing the optimal random effects structure (Matuschek et al., 2017). We began by fitting the maximal random effects structure justified by our design (random intercepts for *participants* and *items*, as well as random slopes for *prosody* and *verb bias*) and followed a backward-fitting model comparison procedure using the Akaike Information Criterion (AIC; Akaike, 1998). The optimal random-effects structure included random intercepts for *participants* and *items.* We then constructed a maximal fixed-effects model, in which we entered *verb bias* (negative level = equi-biased verbs), *prosody* (negative level = modifier prosody), and *group* (negative level = monolingual pupils) and the interactions between them as fixed effects using sum coding (i.e., -0.5, 0.5). To account for any potential adaptation effects, we included *trial order* (centred over the experiment) as a simple predictor. We sequentially trimmed fixed-effect using the AIC, following a backward-fitting model comparison procedure. To interpret significant interactions, we conducted post hoc tests using the *emmeans* package (Lenth, 2024) and applied a Holm-Bonferroni correction (Holm, 1979).

5.2. Gaze Data

The time window of gaze data analysis spanned from the onset of each sentence until 500ms after its end. To clean and preprocess the gaze data, we used the *VWPre* package (Porretta et al., 2016, 2018). 5.92% of samples were flagged as trackloss and 1.89% as off-screen. Trials containing less than 75% valid data were discarded, resulting in 1.7% of trials being removed. One item in the instrument verb, modifier prosody condition was removed due to a coding error which resulted in the same distractor picture being displayed twice. Following data cleaning, we aggregated the remaining gaze samples into 50ms time bins (25 observations per bin) for subsequent statistical analysis.

Past research using the VWP has shown that first fixations in a trial are usually directed to left upper corner (Dahan et al., 2007; Dussias et al., 2013; Meyer & Federmeier, 2008). This effect can be further amplified when preview time is provided, unless participants are required to shift their gaze to the centre of the screen again in order to hear the auditory stimulus. In our data, this upper left corner bias is particularly pronounced and persists throughout a substantial portion of the trial. Moreover, due to a coding error which led to the location of the images not being fully randomised, the image depicting the HA interpretation did not appear in each position on the screen an equal amount of times across conditions, which risks confounding subsequent analyses. We addressed this issue by applying a baseline correction to our data (Mathôt & Vilotijević, 2023; Smith & McMurray, 2022): we aligned gaze data to the onset of the verb, calculated the mean fixation counts in the 100ms window immediately preceding that point, and subtracted these baseline values from all subsequent time bins. We selected verb onset as the alignment point because our auditory stimuli differ minimally in the subject NP and because pre-boundary lengthening and boundary tones occur at the end of the verb in the modifier prosody condition.

The gaze data were analysed with generalised additive mixed-effects models (GAMMs; Wood, 2017) using *mgcv* (Wood, 2017) and *itsadug* (Van Rij et al., 2022) packages. We were interested in participants' preference for the HA interpretation over the LA interpretation in their gaze data. To compute this, we subtracted the looks to the LA interpretation from the looks to the HA interpretation in each bin and used this difference as our response variable (Schouwenaars et al., 2019).

We first constructed a simple model including only our response variable and a smooth for *time*. In order to determine the optimal random-effects structure we tested the inclusion of non-linear random factor smooths through a stepwise model comparison procedure. The optimal random effects structure included smooths by *subject* and by *item*, as well as by *HA position* (i.e. the screen quadrant in which the HA interpretation appeared), to control for the upper left corner bias described above. We modelled our comparisons using binary smooths, which allows for less conservative estimates (Sóskuthy, 2021). In order to investigate eye gaze patterns among our four conditions and two groups, each condition and group combination was coded as a binary (0/1) smooth, resulting in eight smooths used in our model. To account for autocorrelation in the residuals, the AR1 parameter was set based on the *start_value_rho()* function from *itsadug*.

6. Hypothesis and Predictions

The following hypothesis was drawn.

H1: Monolingual pupils will show stronger default parsing preferences for HA, while EAL pupils will utilise all cues available to them showing weaker preferences.

We anticipate that the responses and gaze trajectories of monolingual pupils will be primarily driven by deterministic HA attachment preferences, shaped by default parsing strategies. On the contrary, EAL pupils will seek additional cues to disambiguate and rely more on verb semantics, and potentially prosody, as their parsing preferences may be less established due to exposure to other languages. In our response data, we anticipate interactions of conditions with *group*, i.e., a two-way interaction between *verb bias* and *group*, as well as *prosody* and *group*, or a three-way interaction between *verb bias*, *prosody*, and *group*, with monolingual pupils showing higher HA preference than their EAL peers.

In our gaze data, we generally anticipate more looks to the HA interpretation in monolingual pupils; however, as in our response data, we anticipate that these effects may be modulated by *verb bias* (more HA looks in instrument-biased verbs) or *prosody* (more HA looks in instrument prosody). We expect effects of condition to emerge in the PP-window onwards, as acoustic differences in the stimuli prior to that point may not be salient enough to generate an interpretation until the PP is heard, especially considering that children's processing of prosodic cues may be delayed (Snedeker & Yuan, 2008).

7. Results

7.1. Response Data

Figure 2 presents children's attachment preferences in the response data by *condition* and *group*. As is evident, there was an overall preference for HA across all four conditions and both groups. We report the output of the best-fitting model in Table 3. The inclusion of *trial order* was not warranted. The model indicated a significant interaction between *verb bias* and *group*, which we visualise in Figure 3 below. Post hoc pairwise comparisons showed that, with equi-biased verbs, monolingual pupils show preference for high attachment significantly more than EAL pupils (b = 0.72, SE = 0.33, z = 2.19, p = .028).

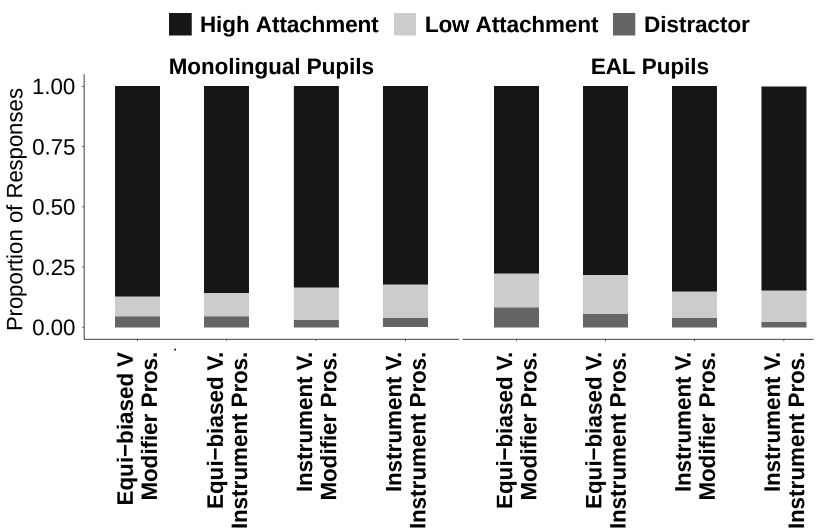

Figure 2. Response data in critical items by group

Table 3. Best-fitting model output for critical items

	Estimate	Std. Error	*z*-value	*p*-value
(Intercept)	2.09	0.27	7.88	<.001***
Group	-0.24	0.28	-0.86	.39
Verb Bias	0.12	0.47	0.27	.79
Verb Bias:Group	0.96	0.34	2.83	.005**

Note: Significance markers: * = p < .05, ** = p < .01, *** = p < .001.

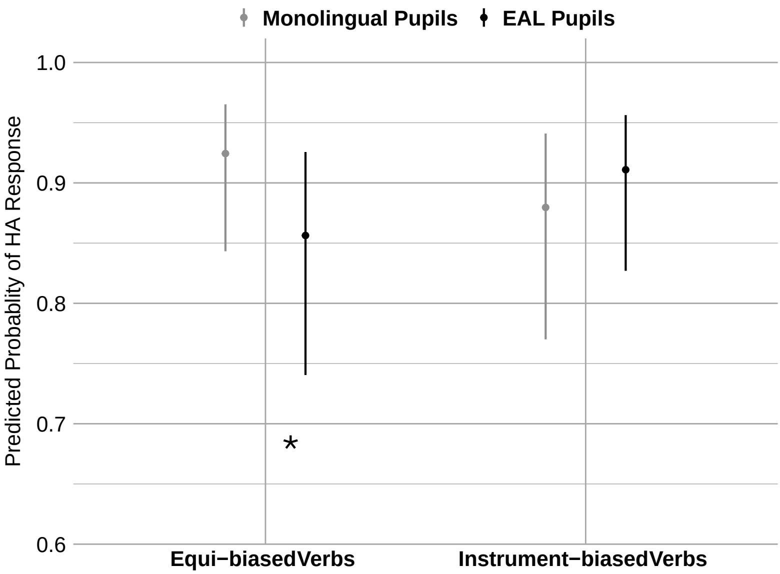

Figure 3. Visualisation of the interaction between group and verb bias with 95% confidence intervals

7.2. Gaze Data

We report the output of our GAM model (R^2 adj = 0.07, deviance explained = 7.45%) in Supplementary Materials on our OSF Repository [1]. It is worth noting that the p-values in a GAMM output are not directly interpretable. We therefore visualised and compared model smooths to interpret our model. We present significant differences plotted on raw data in this paper and include visualisations of model estimates in our OSF repository. In Figure 4, upwards trends above zero on the y axis depict preference for HA, whereas downwards trends below zero on the y axis depict preference for LA. Bold dashed vertical lines indicate time windows of significant difference. For reasons of readability, Figure 4 does not include confidence intervals. For a plot of raw data with confidence intervals, please see our OSF repository.

[1] OSF Repository:
https://osf.io/d2n6x/overview?view_only=2b4d55a7480b428bad73de8c897b6c1f

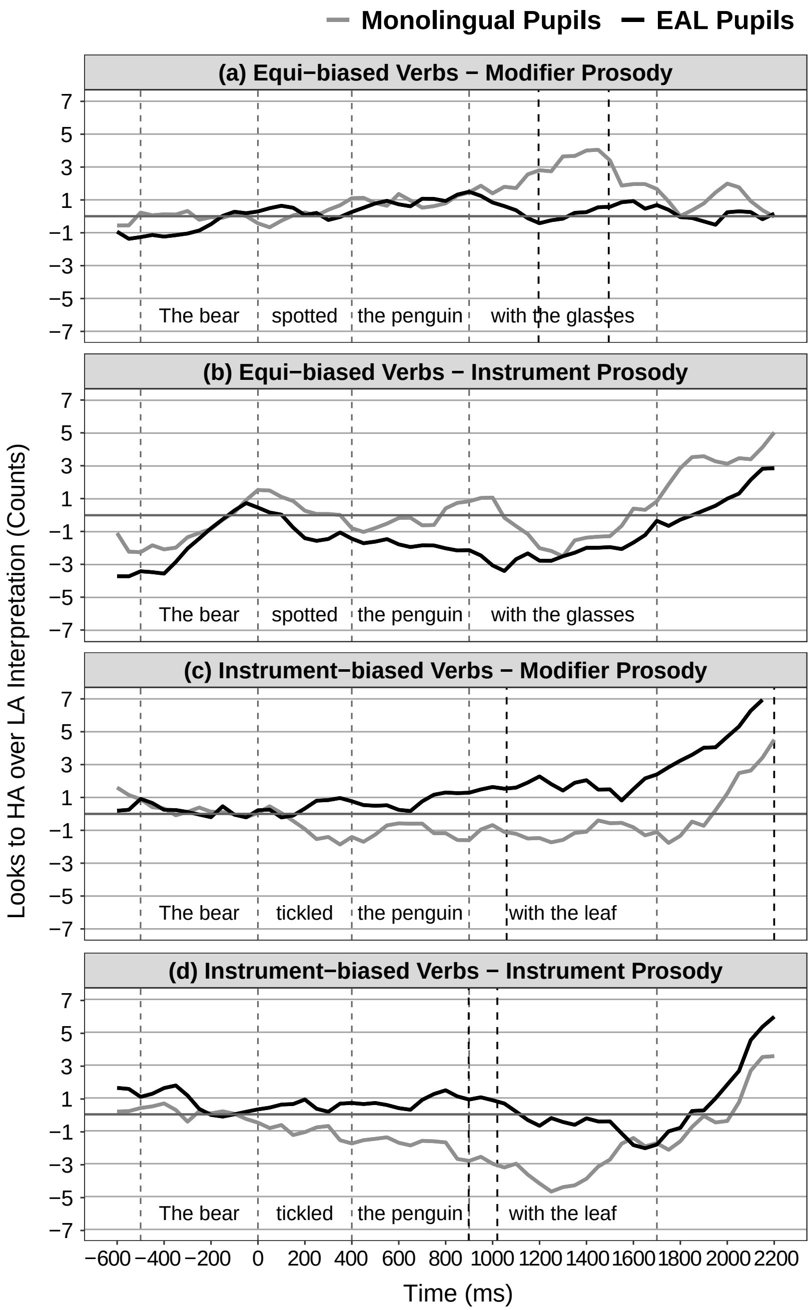

Figure 4. Raw gaze data by condition and group, averaged by participant. Bold dashed vertical lines indicate time windows of significant difference.

Unlike the response data where we noted a clear HA preference across the board, eye movements show that the LA interpretation is indeed considered by participants. In (a), group differences emerge in the PP window, with monolingual pupils showing more looks to the HA interpretation compared to their EAL peers. Therefore, in the lack of clear verb bias and in the presence of modifier prosody, which was expected to prompt LA, monolingual pupils show more HA looks compared to their EAL peers, who show preference for neither interpretation. In (b), where clear verb bias is absent like (a), monolingual pupils show numerically more looks to the HA interpretation compared to their EAL peers, but this difference is not significant at any time point.

In instrument-biased verbs, EAL pupils show more looks to the HA interpretation compared to monolinguals. Specifically, in (c) this difference spans across most of the PP window and until the end of the analysis window. Finally, in (d) where both verb bias and prosody were expected to prompt HA, we observe that EAL pupils show no preference for either interpretation approximately until the end of the PP window, while monolinguals show preference for the LA interpretation in the same time window. This difference becomes significant briefly at the onset of the PP window.

8. Discussion

This study set out to investigate the priority ranking of syntax, semantics, and prosody in the processing of spoken sentences among monolingual and EAL children. We anticipated that monolingual children would show HA preference on the basis of default parsing strategies and that EAL children would show increased sensitivity to additional cues. We expected these differences to surface both in the response and gaze data. In response data, there is no evidence of prosodic effects. With regard to verb bias, we found that monolingual pupils selected the HA interpretation significantly more in equi-biased verbs than in instrument-biased verbs. We interpret this finding as a partial confirmation of our hypothesis: in the absence of verb semantics, the default parsing preference in monolingual pupils is HA. We have no evidence that monolinguals integrate cues in prosody or verb semantics, as instrument-biased verbs are expected to cue HA and monolinguals showed increased HA preference in equi-biased verbs. This pattern is consistent with a least-effort heuristic, i.e., a preference for low-cost, default analyses among monolinguals even when additional cues are available.

In the gaze data, we observe that, in the absence of verb bias (i.e. in equi-biased verbs), monolingual pupils show more looks to the HA interpretation compared to their EAL peers, in line with the response data and consistent with a default HA preference in monolinguals. In instrument-biased verbs, however, the effect is reversed: EAL pupils show more looks to the HA compared to monolinguals. EAL children's increased sensitivity to verb semantics is compatible with the Shallow Structure Hypothesis (Clahsen & Felser, 2006a, 2006b) and monolingual children's prioritisation of syntactic biases is in line with the Late Closure Principle (Frazier, 1979) and adult processing (Clifton et al., 1991; Frazier, 1979; Rayner et al., 1983) of these structures.

Overall, our results suggest that EAL pupils are more sensitive to verb semantics than monolinguals and that verb bias acts as a robust guiding cue for EAL pupils' parsing preferences. Alternatively, it could be argued that the lack of a strong default HA parsing preference in EAL pupils allows for more observable effects of verb semantics. However, we have no evidence of sensitivity to prosodic cues in either group. This finding appears to contrast previous evidence of children's ability to utilise prosodic cues to process syntactic ambiguity (de Carvalho et al., 2016; Giberga et al., 2025; Snedeker & Yuan, 2008). We argue that this difference in findings can be attributed to: (i) the salience of the prosodic cue provided, (ii) the syntactic complexity of the ambiguity used in the stimuli, (iii) the comparisons made in the materials (e.g., prosody vs a no-prosody baseline, or contrasting prosodies), and (i) the complexity of the visual scene.

Our manipulation relied on boundary tones and pre-boundary lengthening without an explicit pause. Past studies in which children show sensitivity prosodic cues do include a prosodic break (Giberga et al., 2025; Snedeker & Yuan, 2008). However, the salience of a prosodic cue does not only depend on the prosodic configuration itself but also on the syntactic complexity of the target structure. For example, de Carvalho et al. (2016) did not use pauses to mark boundaries in ambiguous French sentences, yet their manipulation facilitated disambiguation in children. Notably, that study uses stimuli such as (3) below, which are syntactically less complex than sentences such as (2). The authors found that pre-schoolers can utilise these prosodic boundaries to assign appropriate syntactic categories.

(3) [la petite ferme] [est tres jolie]
'The small farm is very nice'
[la petite] [ferme la fenetre]
'The little girl closes the window'

Some studies establish the contribution of prosody by including a baseline condition in which prosodic cues are not sufficient to guide disambiguation. For example, Giberga et al. (2025), who explore the contribution of prosody in the disambiguation of sentences in Catalan, provide their stimuli in a baseline, "no-prosody" condition, which lacks a prosodic break and features a less salient boundary tone. By contrast, our critical items do not include a "no-prosody" baseline: prosody is always manipulated, so our comparisons are between types of prosody, not on the basis of presence versus absence of prosodic cues. This design choice limits our ability to estimate the absolute contribution of prosody and instead yields contrasts between different prosodic contours.

Finally, the complexity of the visual scene itself can also raise processing demands. For instance, Snedeker & Yuan (2008) use a simpler sentence structure, i.e., "*Tap the frog with the feather*", asking the participants to act out accordingly on a visual scene that only displays the two relevant referents and two distractors. Therefore, the children in their study are required to choose between a *frog holding a feather* or a *feather*, with two distractors present. In our study, each trial presents four pictures, each combining two animals and two objects, and we depict the actions rather than simple referents. This richer layout likely increases visual search and processing costs, which can in turn reduce children's ability to exploit low-salience cues such as prosody.

9. Conclusion

This paper presented a VWP eye-tracking experiment, in which we attempted to tap into the ranking of syntax, semantics, and prosody in EAL children compared to their monolingual peers. On the basis of our findings, it can be argued that the ranking of cues differs between monolingual and EAL children, with the latter prioritising verb semantics over syntactic biases unlike their monolingual peers. However, both groups appear not be sensitive to prosodic cues on the basis of response and gaze data. In the discussion, we noted several methodological aspects of our study which could have led to prosody not producing a reliable effect in the processing of PP attachment ambiguities. These factors should be addressed in future work on cue ranking in attachment ambiguities with monolingual and bilingual children by including a no-prosody baseline condition, strengthening boundary cues with pauses, and reducing display complexity.

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