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Preschoolers' Real-Time Eye Movements Reveal Sensitivity to Connective Meanings During Word Learning

Elizabeth Swanson, Hugh Rabagliati, and Alex de Carvalho

1. Introduction

Children produce basic connectives such as *so*, *and*, and *but* by around age 3 (Bloom et al., 1980; Braunwald, 1985), but prior research has found that children do not seem to understand connectives, especially *but*, in an adult-like way until at least age 7 (Kail & Weissenborn, 1984; Skarabela et al., 2023b; Spenader, 2018). In this study, we aimed to shed light on the factors that affect preschool children's comprehension of the connectives *but* and *so* in real time during a novel word-learning task. We used eye-tracking in the hope of reducing task demands that have been at play in previous studies, and specifically investigated the role of executive function skills and socioeconomic status. Our results indicate that children as young as 4 are sensitive to the difference between *so* and *but* in online processing and novel word interpretations, but they do not reliably draw the contrastive inferences from *but* that adults typically do. We did not find clear evidence that executive function—specifically, cognitive control—contributed to children's comprehension of *but*, although higher socioeconomic status correlated with more contrastive interpretations. Moreover, our findings suggest that drawing adult-like contrastive inferences is effortful for children and easily blocked by the initial semantic context of a sentence.

1.1. Children's acquisition of connectives: Previous work

In corpus studies of children's naturalistic productions, they have been found to produce basic connectives, including *so* and *but*, before age 3 (Bloom et al., 1980; Braunwald, 1985). Preschool children have been reported to make few apparent errors in their uses of connectives (French, 1981; Gallivan, 1986),

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although recent work suggests that children younger than 4 use *but* in less adult-like ways than older children (Skarabela, 2023a).

In contrast, comprehension studies have claimed that children do not understand connectives in an adult-like manner until at least age 7. However, many of these studies have asked children to provide metalinguistic judgments or select the connective that best completes a sentence (Cain & Nash, 2011; Kail & Weissenborn, 1984). These tasks place additional cognitive demands on children that are not present in naturalistic language use, and the results may therefore mask an earlier underlying competence.

Spenader (2018) lessened task demands by testing Dutch-speaking children's understanding of connectives using a pronoun resolution task. Children heard sentences of the form "Diego asked Sponge Bob to tidy up, [but/because] he didn't feel like doing it" and were then asked a question such as "Who didn't feel like tidying up?" Adults most naturally interpreted *he* as referring to Sponge Bob in the *because* version of the sentence, and as referring to Diego in the *but* version. However, 7-year-olds were at chance on *but* trials; only 8- to 10-year-olds showed an effect of condition, though not at adult levels. This demonstrates that older children have some understanding of the contrastive nature of *but*.

In a series of studies, Skarabela et al. (2023b) examined the developmental trajectory of children's comprehension of *so* and *but* as well as possible factors contributing to their struggles with *but*. Children ages 2 to 7 completed a novel word learning task in which they heard sentences such as "It was a summer day, [so/but] Mary brought a *ploom*." At the same time, children saw pairs of images: one that was semantically associated with the initial clause of the sentence (here, a bicycle) and one that contrasted with the expectations created by the initial clause (here, a sled). Children were asked to point to the picture corresponding to the novel word (e.g., "Can you point to the *ploom*?"). The results showed that in the *so* condition, 2-year-olds were already above chance in choosing the semantically associated image in the *so* condition, and as children's age increased, they chose the associated image increasingly often, becoming more adult-like. Adults were at ceiling in the *so* condition, strongly preferring the semantically associated image. In the *but* condition, however, 2-year-olds were at chance, and children became increasingly likely to select the semantically associated image—not the contrasting image—between ages 3 and 6. Even 7-year-olds were at chance on *but* trials, whereas adults chose the contrasting image the majority (75%) of the time. These results provide evidence that during the preschool years, children do not generally draw the same contrastive inferences from sentences containing *but* as adults do.

In several follow-up experiments, Skarabela et al. (2023b) found similar results when they manipulated various aspects of the task design (e.g., presenting the images only when children are asked to select one of them) and even when they made the contrastive inference explicit and removed the word-learning element (e.g., "The day was cold. When the day is cold, you should put your winter clothes on, [so/but] Katy put on a...").

Thus, previous studies have found striking evidence that children are not adult-like in their interpretations of connectives until the school years. Yet, the fact remains that they produce connectives with fluency in naturalistic speech before preschool, creating a puzzling production-comprehension asymmetry.

1.2. Factors underlying children's difficulties with *but*

It remains an open question what the source(s) of children's struggles with understanding connectives, and *but* in particular, may be. One line of thought centers around the idea that *but* is a conventional implicature (Grice, 1961) which does not contribute to the truth-conditional meaning of an utterance, and that children's delays are similar to those observed with conversational implicatures (e.g., that *some* implies *some but not all*; Papafragou & Skordos, 2016). However, children do not yet appear to treat *but* in an adult-like way by age 4 to 5, which is when they gain facility with conversational implicatures. Furthermore, if it were the case that children struggled with the contrastive nature of *but* altogether, we might expect them to show more errors in naturalistic production.

Another possibility is that children do not lack a general understanding of the contrastive nature of *but*, but rather have difficulty arriving at the intended dimension of contrast in specific contexts. *But* can encode various types of contrasts (Seligman, 1985) and it may be easier for children to identify the relevant dimension of contrast within a naturalistic situation.

A third factor that may complicate children's comprehension is the observation that *but* often requires a listener to revise their expectations about the interpretation of a sentence. Preschool children have previously been found to exhibit a 'kindergarten-path effect' where they struggle to reanalyze an initial interpretation of a sentence when conflicting information is presented later on (Trueswell et al., 1999; Weighall, 2008). For instance, in Trueswell et al. (1999), participants heard sentences such as "Put the frog on the napkin onto the book." Both adults and children initially (upon hearing *Put the frog on the napkin...*) looked toward an empty napkin as the destination for the frog. Upon hearing *onto the book*, adults shifted their gaze toward a book. However, children tended to keep looking at the original destination (the empty napkin) and to erroneously place the frog there. Preschool children's ability to revise their interpretations of garden-path sentences has been found to be associated with both nonlinguistic executive function skills, particularly cognitive control (Hsu & Novick, 2016; Woodard et al., 2016), and socioeconomic status, as a proxy for global language variation (Huang & Hollister, 2019).

It is possible that a similar phenomenon to the kindergarten-path effect could be at play in sentences containing *but*: Children might form a prediction about the sentence meaning based on the initial clause (*It was a summer day...*) and have difficulty revising this prediction based only on the connective *but*. In the current study, we focused on the potential role of revision, cognitive control, and socioeconomic status in children's comprehension of sentences containing *but*.

2. Research questions

In the experiment reported here, we sought to address two main research questions. First, although previous research has suggested that adults draw on the information conveyed by causal connectives incrementally as they process sentences (Koornneef & Sanders, 2013; Traxler et al., 1997), no one has to our knowledge examined children's processing of causal and contrastive connectives in real time. Thus, in a task with stimuli similar to Skarabela et al. (2023b) but adapted to French, we used eye-tracking to investigate how the connectives *so* and *but* influenced 4- to 6-year-old children's real-time sentence comprehension and interpretations of novel words. This allowed us to examine whether children show sensitivity to the contrastive nature of *but* that can be detected with an implicit measure, even if their explicit responses do not reflect this knowledge. In addition, we wished to see whether children would show signs of making a prediction about the sentence interpretation upon hearing the initial semantic context, by looking early at the image associated with the initial context and then failing to switch their gaze to the contrasting image upon hearing *but*.

Second, we investigated whether children's ability to draw adult-like contrastive inferences from sentences containing *but* was associated with their cognitive control skills and socioeconomic status. We measured cognitive control via a Flanker task (Rueda et al., 2004), which was used in a previous study that found a relationship between preschoolers' cognitive control and their ability to revise interpretations of garden-path sentences (Woodard et al., 2016). If there is both an effect of cognitive control and eye-tracking signatures of early predictions, this would provide evidence that at least part of children's difficulty with *but* is due to their struggles with revising an initial sentence interpretation. In addition, we used the number of years of maternal education as a proxy for socioeconomic status and variation in the linguistic input addressed to children. If socioeconomic status predicts *but* comprehension, this would suggest that difficulty with *but* during development might be related to linguistic knowledge, instead of or in addition to cognitive control.

The sample size, procedure, and analyses were preregistered prior to beginning data collection.¹

3. Procedure

3.1. Participants

The final sample included seventy-one 4- to 6-year-old children (24 4-year-olds, 23 5-year-olds, 24 6-year-olds) and a baseline group of 24 adults, all of whom were monolingual French speakers. Children completed both the novel word learning task and the Flanker task, and adults completed only the novel word learning task.

1. The detailed preregistration and all code and analyses are available at https://osf.io/yqkqj/?view_only=512456e635c045d08663aededa60cdc9.

3.2. Procedure: Novel word learning task

The novel word learning task used a looking-while-listening paradigm in which participants were seated in front of a computer screen with an eye-tracker (eye-link portable duo) attached to the base. Visual stimuli appeared on the computer screen and participants listened to the audio through headphones.

After a five-point calibration, participants saw a video introducing them to an alien puppet named Lola who invited them to learn some words from her alien language. The task began with three training trials with familiar words and then 20 test trials with novel words (10 *so* trials and 10 *but* trials). The time course of a test trial is illustrated in Figure 1.

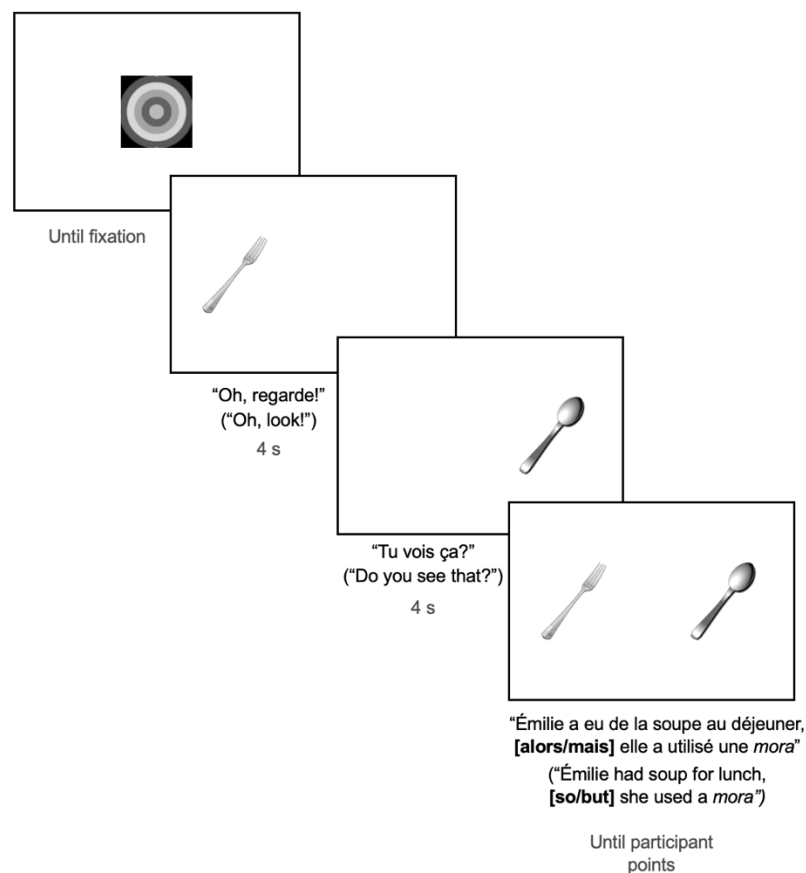


Figure 1. Structure of a test trial for the novel word learning task.

Each trial began with an attention-grabber. Once the participant's eyes had fixated on the center of the screen, two images of familiar objects were presented on the left and right sides of the screen (e.g., a fork and a spoon). Each image was

previewed individually for 4 seconds before the images appeared together. Then the target sentence began (e.g., “*Émilie a eu de la soupe au déjeuner, [alors/mais] elle a utilisé une mora*” – “Émilie had soup for lunch, [so/but] she used a *mora*”). After the target sentence, participants were asked to point to the image referred to by the novel word (e.g., “*Montre-moi la mora!*” – “Show me the *mora!*”).

We thus collected both the eye-tracking data as the sentence unfolded and participants’ explicit pointing responses at the end of the trial. In the *so* condition, the expected adult-like pointing response is to select the image that is semantically associated with the initial clause (the spoon). In the *but* condition, it is to select the image that contrasts with the initial semantic context (the fork).

The type of the initial context (e.g., *Emily had [soup/sausages] for lunch...*), type of image (associated vs. contrasting) on each screen side, and which sentences contained *but* vs. *so* were all counterbalanced across participants.

3.3. Procedure: Flanker task

Children completed the Flanker task (adapted from Woodard et al., 2016) on a laptop computer. During the task, a row of five fish appeared at the center of the screen, as in Figure 2. Children were instructed to focus their attention on the fish in the middle of the row and to press one of two computer keys depending on whether the middle fish was facing left or right, or to press no key if the middle fish was surrounded by empty fishbowls (no-go trials, as in Figure 2c). This task measures children’s ability to disregard irrelevant information (from the surrounding fish), to inhibit a prominent response (no-go trials), and to flexibly switch between different rules for responding (no-go trials vs. trials where the child must respond).

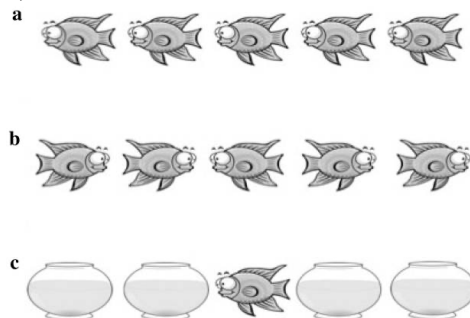


Figure 2. Structure of (a) congruent, (b) incongruent, and (c) no-go test trials for the Flanker task (image adapted from Woodard et al., 2016).

Children first completed 12 practice trials to teach them how to do the task, during which they received feedback about their answers. Then they completed 36 test trials, divided into 12 trials in each of three conditions: (a) congruent (the middle fish was facing the same direction as the surrounding fish), (b) incongruent (the middle fish was facing the opposite direction from the surrounding fish) or

(c) no-go (the middle fish was surrounded by fishbowls). The direction that the middle fish faced was counterbalanced and the order of the trials was randomized.

Reaction time (in milliseconds) and accuracy were measured as the dependent variables for the Flanker task.

4. Results

In eye gaze analyses, we excluded looks away from the screen, so proportion of looks to the associated and contrasting image are complementary and we report only the proportion of looks to the associated image. Trials were excluded if the eye-tracker had more than 25% track loss (23% of trials). We did not find significant effects of children's age group for any analyses reported and therefore present the results for all children (4-, 5-, and 6-year-olds) averaged together. Graphs by age group may be found in the OSF repository at <https://osf.io/yqkgij/>.

4.1. Novel word learning task: Pointing responses

Figure 3 plots participants' proportion of points toward the semantically associated image in *but* and *so* trials. Children chose the semantically associated image at above-chance levels on both *so* ($M = 0.87$; CI: [0.83, 0.91]) and *but* ($M = 0.70$; CI: [0.63, 0.77]) trials, while adults selected the semantically associated image on nearly all *so* trials ($M = 0.99$; CI: [0.98, 1.00]), in contrast to *but* trials ($M = 0.26$; CI: [0.15; 0.37]), where they tended to select the contrasting image.

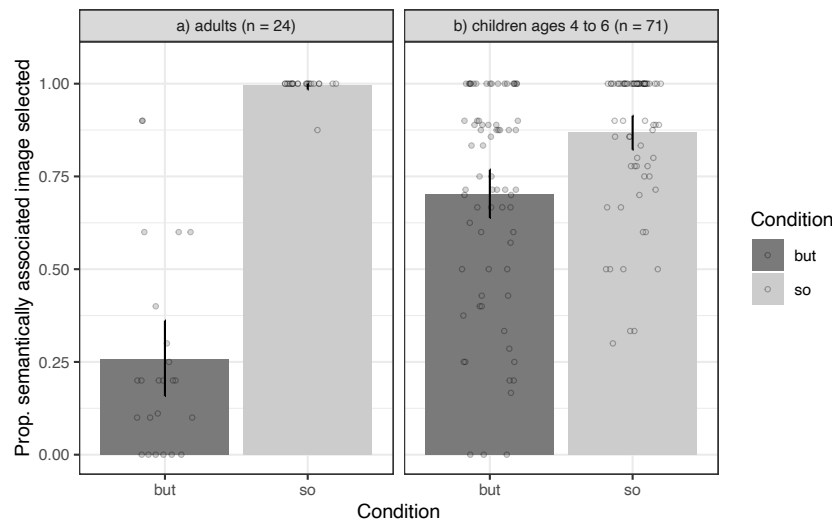


Figure 3. Mean proportion of trials on which participants selected the semantically associated image in the *but* (darker bar) and *so* (lighter bar) conditions for (a) adults and (b) children. Error bars show bootstrapped 95% confidence intervals. Dots represent individual participant means.

The pointing data was analyzed via generalized linear mixed-effects models using the R package lme4 (Bates et al., 2015), with separate models for children and adults. In each model, the outcome was whether the participant pointed to the semantically associated image, with a fixed predictor for condition (*but* vs. *so*) and random participant and item effects. The model found a significant effect of condition for both children ($\beta = 0.15$; $SE = 0.02$; $p < 0.01$) and adults ($\beta = 0.73$; $SE = 0.03$; $p < 0.01$), such that both groups selected the semantically associated image more in the *so* condition than the *but* condition.

4.2. Novel word learning task: eye movements

We then examined the time course of participants' looks as they heard the sentences unfold. Figure 4 plots children's and adults' average proportion of looks to the semantically associated image from 1000 ms before the connective onset until 4000 ms afterwards.

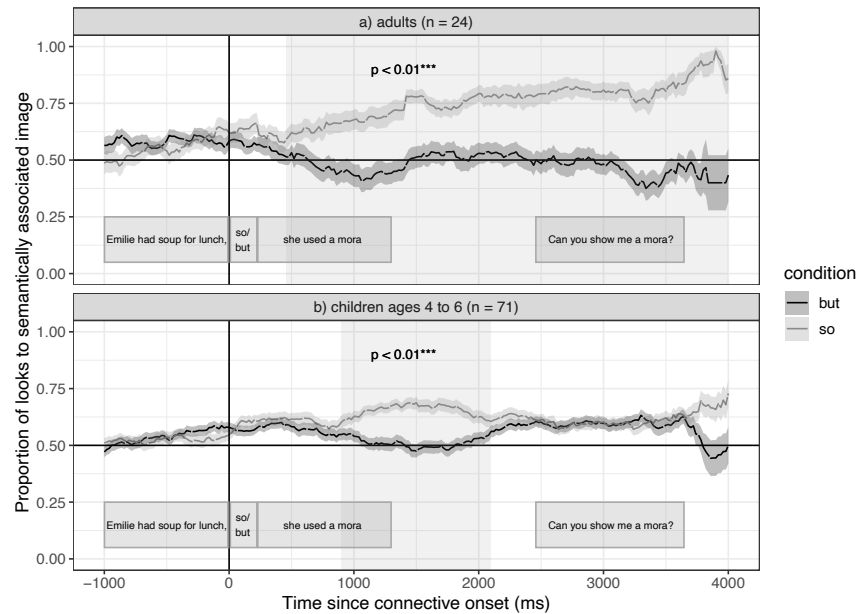


Figure 4. Proportion of looks to the semantically associated image, time-locked to the connective onset (vertical black line) for (a) adults and (b) 4- to 6-year-old children, in the *but* condition (darker curve) and *so* condition (lighter curve). Error bars represent the standard error of the mean. The lengths of the text boxes at the bottom correspond to the average durations of the audio segments in test sentences.

To analyze the time course of eye movements, we performed a cluster-based permutation analysis to find the time windows with a significant difference

between conditions (as in: de Carvalho et al., 2021; formally presented in Maris & Oostenveld, 2007). This was done by running a paired t-test for the effect of condition in each time bin in the eye-tracking data (with the preregistered threshold $t = 1.5$). Adjacent time bins with a test statistic over the threshold were grouped together into time clusters, and the test statistics within each time cluster were summed to obtain a sum statistic. We then performed 1000 simulations in which the eye-tracking data was shuffled and the same process was repeated, creating a distribution of simulated sum statistics that corresponds to what we would expect to get by chance. A time cluster from the actual data showed a significant effect of condition if the absolute value of its sum statistic was greater than at least 95% of the simulated sum statistics (ensuring a p -value < 0.05).

The cluster-based permutation analysis revealed a time window between 900 and 2100 ms after the connective onset when children were significantly more likely to look at the semantically associated image on *so* trials than on *but* trials ($p < 0.01$). For adults, there was a significant time window with an effect in the same direction from 460 to 4120 ms after the connective onset ($p < 0.01$).

4.3. Relating pointing responses to eye movements

To gain a greater understanding of the relationship between participants' eye movements and their pointing responses, we carried out a post-hoc examination of their eye gaze patterns when they pointed to the correct (adult-like) image vs. when they pointed to the incorrect image (see Figure 5).

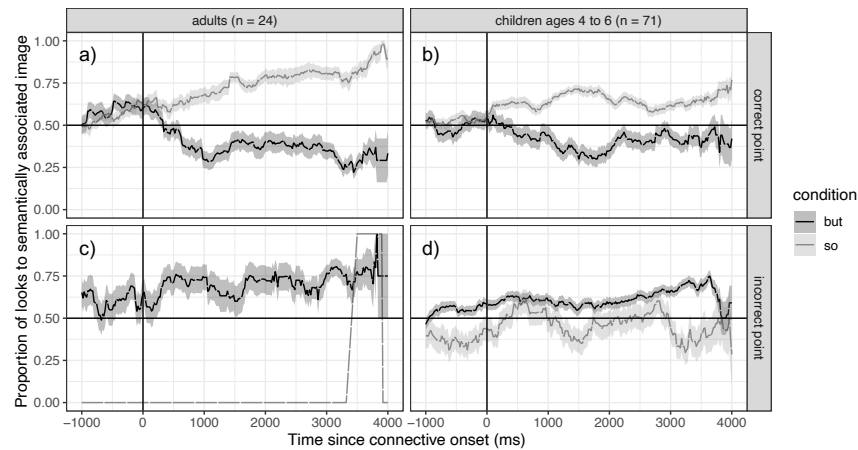


Figure 5. Proportion of looks to the semantically associated image, time-locked to the connective onset (vertical black line) for (a) adults on trials when they pointed correctly, (b) children when they pointed correctly, (c) adults when they pointed incorrectly, and (d) children when they pointed incorrectly, in the *but* condition (darker curve) and *so* condition (lighter curve). Error bars represent the standard error of the mean.

When adults ultimately pointed to the correct image, in both conditions they tended to look at the semantically associated image before the connective onset, with their looks diverging in the expected direction soon after they heard the connective. When children pointed to the correct image, they did not show a clear preference for either image before the connective onset, but their looks diverged in the expected direction after they heard the connective.

In contrast, when adults and children chose the incorrect image on *but* trials, they preferred the incorrect (semantically associated) image even before the connective onset and continued looking at it throughout the trial. On *so* trials when children chose the incorrect image, they also tended to look at the incorrect (contrasting) image before the connective onset and showed no clear pattern after the connective onset. There was only one *so* trial on which an adult chose the incorrect image.

4.4. Relating performance on the Flanker task and socioeconomic status to children's connective interpretations

Following Woodard et al. (2016), we calculated three types of measures of cognitive control from the Flanker task data for each child. Flanker congruency costs consisted of the differences in reaction time and accuracy on incongruent vs. congruent trials. This measures the cost to the child's reaction time and accuracy when the middle fish was facing the opposite direction from (and thus visually incongruent with) the fish surrounding it. Flanker switch costs were defined as the differences in reaction time and accuracy between trials that were of a different type than the previous trial vs. trials that were of the same type as the previous trial. This represents the cost to the child when there was a change in the information they had to use to successfully complete the trial.² Flanker no-go cost was the difference between omission errors on congruent or incongruent trials (i.e., the child incorrectly did not respond) and correct non-responses on no-go trials. This captures the cost of having to inhibit a response on the no-go trials. Higher costs correspond to lower cognitive control skills.

We assessed the relationship between cognitive control, socioeconomic status, and children's pointing responses during *but* sentences by creating a linear regression model (as in Woodard et al., 2016) with the proportion of correct pointing responses (to the contrasting image) on *but* trials as the outcome variable, and the fixed predictors Flanker congruency accuracy, Flanker congruency reaction time, Flanker switch accuracy, Flanker switch reaction time, Flanker no-go cost, age in months, years of maternal education, and proportion of correct responses on *so* trials (with all variables converted to z-scores). Including the proportion of correct responses on *so* trials allowed us to distinguish the ability to

2. In the preregistration, we planned to calculate Flanker Congruency Cost and Flanker Switch Cost by taking the average of the z-scores for differences in reaction time and accuracy. However, we grew concerned that this could obscure individual effects of reaction time or accuracy, so we report the two measures separately here.

revise expectations in *but* sentences from more general linguistic abilities that also underlie children's processing of *so* sentences. Among these predictors, we found a significant effect of years of maternal education ($\beta = 0.34$; $SE = 0.16$; $p = 0.04$) and of proportion of correct points in the *so* condition ($\beta = -0.52$; $SE = 0.16$; $p < 0.01$).

We then ran a linear regression model with the proportion of correct looks (to the contrasting image) on *but* trials as the outcome variable and the same fixed predictors as above except for proportion of correct looks, rather than points, in the *so* condition. In this model, there was a significant effect of Flanker no-go cost ($\beta = 0.39$; $SE = 0.15$; $p = 0.01$) and a marginal effect of proportion of correct looks in the *so* condition ($\beta = -0.31$; $SE = 0.16$; $p = 0.06$). However, the effect of Flanker no-go cost appears to be driven by three children with particularly high no-go costs (z-score > 3) and is not significant if they are excluded.

5. Discussion

The current study examined 4- to 6-year-old French-speaking children's comprehension of the connectives *so* (*alors*) and *but* (*mais*) during real-time sentence processing and evaluated the roles of cognitive control and socioeconomic background in children's understanding of *but*. Our results demonstrate that French-speaking preschool children and adults are sensitive to the difference between *so* (*alors*) and *but* (*mais*) both during processing and in the final interpretations they assign to novel words, but preschoolers show key differences from adults.

In their pointing responses, children were significantly more likely to select the semantically associated image in the *so* condition than the *but* condition. However, they did not reliably draw adult-like contrastive inferences; they chose the semantically associated image the majority of the time in both conditions. This replicates the results of Skarabela et al. (2023b) in English and previous comprehension studies reporting difficulties with *but* through the preschool years (Cain & Nash, 2011; Kail & Weissenborn, 1984; Spenader, 2018).

In the eye gaze data, the cluster analysis found a time period after the connective offset where children were significantly more likely to look at the semantically associated image in the *so* condition than the *but* condition—similar to adults, though the significant time period was longer for adults than children. This is the first evidence to indicate that preschool children show sensitivity to the difference between *but* and *so* during real-time sentence processing.

Looking more closely at the relationship between children's eye movements and their pointing responses, we found that when adults ultimately chose the contrasting image on *but* trials, they showed signs of revising an initial prediction: They tended to look at the semantically associated image before the connective and shift their gaze to the contrasting image after the connective. However, children did not show a clear preference for either image before the connective, only looking more to the contrasting image after the connective. When children

and adults pointed to the (incorrect) semantically associated image on *but* trials, they preferred the associated image throughout the entire trial.

Finally, we found that socioeconomic status (years of maternal education) predicted children's correct pointing responses on *but* trials. We also reported a fragile effect of Flanker no-go cost on children's correct looks in the *but* condition, driven by outliers, from which we are hesitant to draw conclusions. Our results did not contain clear evidence that the Flanker measures of cognitive control were associated with children's ability to draw contrastive inferences in *but* sentences.

Together, these findings indicate that preschool children can sometimes draw contrastive inferences from sentences containing *but*, in both real-time processing and final novel word interpretations. However, these inferences seem to be easily blocked by a bias toward relying on the initial semantic context, as can be seen in children's tendency to look at the semantically associated image throughout the entire *but* trial when that is the image they ultimately select. When children did choose the contrasting image on *but* trials, they did not show signs of revising an initial preference for the semantically associated image. This, and the lack of an association with cognitive control, suggests that children at this age do not seem to be engaging in revision when they do successfully draw contrastive inferences.

Given the evidence that children use *but* fluently in naturalistic production by the preschool years (French, 1981; Gallivan, 1986; Skarabela, 2023a) and that they are sensitive to the difference between *so* and *but* in our comprehension task, it seems highly unlikely that they lack the capacity to draw contrastive inferences. Instead, we suspect that children's non-adult-like behavior with *but* reflects either difficulty identifying the specific dimension of contrast (Seligman, 1985), and/or a lower weighting than adults of *but* as a cue to sentence interpretation and novel word learning. Recent adult corpus work has found a surprisingly high degree of substitutability between different connectives (Rohde et al., 2018), which suggests that connectives may not map to unique discourse relations as well as one may think. In our task, even adults did not show as clear a preference for the contrasting image on *but* trials (74% of points) as they did for the associated image on *so* trials (99% of points). Participants are asked in comprehension tasks such as our own to rely only on the presence of the connective *but* to prompt a contrastive inference, but in naturalistic language use, other lexical and semantic information may be stronger cues to sentence interpretation. Thus, children may have good reason to rely more strongly on the semantic content of the initial clause than the connective, even if they have some notion that *but* is contrastive.

It is an open question how children eventually become adult-like in their understanding of connectives, particularly *but*. Formal schooling and increasing literacy may play a role, as children often learn explicitly about connective meanings in school (Tellings & de Vries, 2020), which could help highlight the range of contrasts marked by *but*. The effect of socioeconomic status that we found for correct pointing responses in the *but* condition may support this suggestion, as it could reflect variation in children's amount and type of language input and interaction (Anderson et al., 2021; Hart & Risley, 1995; Hirsh-Pasek et al., 2015; Rowe & Snow, 2020); for instance, greater exposure to literary language

could result in more adult-like interpretations of *but*. Future work should examine this proposal carefully and aim to shed further light on the conditions in which young children are able to draw contrastive inferences from sentences containing *but*.

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