Supplementary Materials for Bilingual children’s comprehension of code-switching at an uninformative adjective

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## Growth Curve Analysis

As described in the main text, we conducted a growth curve analysis using the time window of 400 – 2000ms after the noun onset, with looking time data binned in 100ms blocks. The final model was built and selected through an iterative process (See Table 1 for terms in each model; Mirman, 2017). First, we constructed a baseline model which contained only linear and quadratic time terms as fixed effects and random slopes on the random effect of participant (See Table 2). For Model 1, we added the fixed effect of trial type, which was coded using a simple contrast coding scheme. The results of Model 1 are presented in Table 3. Compared to baseline, the addition of trial type significantly improved the model (see Table 4), thus this variable was retained for subsequent models. For Model 2, we next added the interaction between trial type and the linear time term (See Table 5). Compared to Model 1, the addition of this interaction did not statistically significantly improve the model (see Table 6) and was removed for subsequent models. Model 1 served as the final model for our analysis on the effect of trial type and the baseline model for our analyses on the effects of language dominance, testing location, socioeconomic status, and vocabulary.

For each subsequent model, the variable of interest was added as a main effect and in an interaction with trial type. In Model 3, we investigated the effect of language dominance (See Table 7. Compared to Model 1, the addition of language dominance did not significantly improve the model (See Table 8). In Model 4, we investigated the effect of testing location (See Table 9). Compared to Model 1, the addition of testing location statistically significantly improved the model (See Table 10). In Model 5, we investigated the effect of socioeconomic status (See Table 11. Compared to Model 1, the addition of socioeconomic status statustically significantly improved the model (See Table 12). In Model 6, we investigated the effect of vocabulary (See Table 13). Compared to Model 1, the addition of vocabulary statistically significantly improved the model (See Table 14).

Table 1:

*Fixed effects in each model in the iterative process*

| Model | Fixed effects |
| --- | --- |
| Base model | Linear time + quadratic time |
| Model 1 | Linear time + quadratic time + trial type |
| Model 2 | Linear time + quadratic time + trial type + trial type x linear time |
| Model 3 | Linear time + quadratic time + trial type + language dominance + trial type x language dominance |
| Model 4 | Linear time + quadratic time + trial type + testing location + trial type x testing location |
| Model 5 | Linear time + quadratic time + trial type + socioeconomic status + trial type x socioeconomic status |
| Model 6 | Linear time + quadratic time + trial type + vocabulary + trial type x vocabulary |

*Note.* Each model had the same random effect structure including linear and quadratic time as random slope for participants

Table 2:

*Baseline Model*

|  | Estimate | 95% CI |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fixed effects** |  |  |  |  |  |
| Intercept | 0.76 | [0.72, 0.79] | 43.06 | 29.43 | < .001 |
| Time (Linear) | 0.29 | [0.14, 0.43] | 3.86 | 29.45 | .001 |
| Time (Quadratic) | -0.27 | [-0.32, -0.23] | -12.36 | 29.12 | < .001 |
| **Random effects** |  | **Variance** |  |  |  |
| Participant | Intercept | 0.008 |  |  |  |
|  | Time (Linear) | 0.155 |  |  |  |
|  | Time (Quadratic) | 0.002 |  |  |  |

*Note.* Equation = *proportion looking time ~ [time (linear) + time (quadratic)] + ([time (linear) + time (quadratic)] || participant)*

Table 3:

*Model 1, addition of trial type as fixed factor*

|  | Estimate | 95% CI |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fixed effects** |  |  |  |  |  |
| Intercept | 0.76 | [0.72, 0.79] | 43.05 | 29.42 | < .001 |
| Time (Linear) | 0.29 | [0.14, 0.43] | 3.86 | 29.46 | .001 |
| Time (Quadratic) | -0.27 | [-0.32, -0.23] | -12.36 | 29.09 | < .001 |
| Trial type | -0.03 | [-0.05, -0.01] | -3.43 | 6,100.82 | .001 |
| **Random effects** |  | **Variance** |  |  |  |
| Participant | Intercept | 0.008 |  |  |  |
|  | Time (Linear) | 0.154 |  |  |  |
|  | Time (Quadratic) | 0.002 |  |  |  |

*Note.* Equation = *proportion looking time ~ [time (linear) + time (quadratic)] + trial type + ([time (linear) + time (quadratic)] || participant)*

Table 4:

*ANOVA comparison of Model 1 to the baseline model*

| Model | Number of parameters | AIC | BIC | Log-likelihood | Deviance | *X*2 | *df* | *p* |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Base model | 7.00 | 6,043.90 | 6,090.99 | -3,014.95 | 6,029.90 | NA | NA | NA |
| Model 1 | 8.00 | 6,034.12 | 6,087.95 | -3,009.06 | 6,018.12 | 11.78 | 1.00 | 0.00 |

Table 5:

*Model 2, addition of interaction between trial type and time (linear)*

|  | Estimate | 95% CI |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fixed effects** |  |  |  |  |  |
| Intercept | 0.76 | [0.72, 0.79] | 43.09 | 29.42 | < .001 |
| Time (Linear) | 0.29 | [0.14, 0.44] | 3.85 | 29.44 | .001 |
| Time (Quadratic) | -0.27 | [-0.32, -0.23] | -12.37 | 29.07 | < .001 |
| Trial type | -0.03 | [-0.05, -0.02] | -3.49 | 6,100.99 | < .001 |
| Trial type x Time (Linear) | -0.06 | [-0.14, 0.02] | -1.46 | 6,103.57 | .144 |
| **Random effects** |  | **Variance** |  |  |  |
| Participant | Intercept | 0.008 |  |  |  |
|  | Time (Linear) | 0.156 |  |  |  |
|  | Time (Quadratic) | 0.002 |  |  |  |

*Note.* Equation = *proportion looking time ~ [time (linear) + time (quadratic)] + trial type + trial type:time (linear) + ([time (linear) + time (quadratic)] || participant)*

Table 6:

*ANOVA comparison of Model 2 to Model 1*

| Model | Number of parameters | AIC | BIC | Log-likelihood | Deviance | *X*2 | *df* | *p* |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model 1 | 8.00 | 6,034.12 | 6,087.95 | -3,009.06 | 6,018.12 | NA | NA | NA |
| Model 2 | 9.00 | 6,033.98 | 6,094.54 | -3,007.99 | 6,015.98 | 2.14 | 1.00 | 0.14 |

Table 7:

*Model 3, addition of language dominance*

|  | Estimate | 95% CI |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fixed effects** |  |  |  |  |  |
| Intercept | 0.76 | [0.72, 0.79] | 44.35 | 29.44 | < .001 |
| Time (Linear) | 0.29 | [0.14, 0.43] | 3.86 | 29.46 | .001 |
| Time (Quadratic) | -0.27 | [-0.32, -0.23] | -12.37 | 29.08 | < .001 |
| Trial type | -0.03 | [-0.05, -0.01] | -3.39 | 6,101.58 | .001 |
| Language dominance | -0.05 | [-0.11, 0.02] | -1.36 | 29.44 | .183 |
| Trial type x Language dominance | 0.01 | [-0.03, 0.05] | 0.35 | 6,101.58 | .727 |
| **Random effects** |  | **Variance** |  |  |  |
| Participant | Intercept | 0.008 |  |  |  |
|  | Time (Linear) | 0.154 |  |  |  |
|  | Time (Quadratic) | 0.002 |  |  |  |

*Note.* Equation = *proportion looking time ~ [time (linear) + time (quadratic)] + trial type + language dominance + trial type x language dominance ([time (linear) + time (quadratic)] || participant)*

Table 8:

*ANOVA comparison of Model 3 to Model 1*

| Model | Number of parameters | AIC | BIC | Log-likelihood | Deviance | *X*2 | *df* | *p* |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model 1 | 8.00 | 6,034.12 | 6,087.95 | -3,009.06 | 6,018.12 | NA | NA | NA |
| Model 3 | 10.00 | 6,036.19 | 6,103.48 | -3,008.10 | 6,016.19 | 1.93 | 2.00 | 0.38 |

Table 9:

*Model 4, addition of testing location*

|  | Estimate | 95% CI |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fixed effects** |  |  |  |  |  |
| Intercept | 0.75 | [0.71, 0.78] | 43.20 | 29.72 | < .001 |
| Time (Linear) | 0.29 | [0.14, 0.43] | 3.87 | 29.47 | .001 |
| Time (Quadratic) | -0.27 | [-0.31, -0.23] | -12.44 | 29.05 | < .001 |
| Trial type | -0.05 | [-0.07, -0.03] | -4.67 | 6,103.15 | < .001 |
| Testing location | -0.07 | [-0.14, 0.00] | -1.98 | 29.71 | .057 |
| Testing location x Trial type | -0.09 | [-0.13, -0.05] | -4.16 | 6,103.14 | < .001 |
| **Random effects** |  | **Variance** |  |  |  |
| Participant | Intercept | 0.007 |  |  |  |
|  | Time (Linear) | 0.154 |  |  |  |
|  | Time (Quadratic) | 0.002 |  |  |  |

*Note.* Equation = *proportion looking time ~ [time (linear) + time (quadratic)] + trial type + testing location + testing location x trial type + ([time (linear) + time (quadratic)] || participant)*

Table 10:

*ANOVA comparison of Model 4 to Model 1*

| Model | Number of parameters | AIC | BIC | Log-likelihood | Deviance | *X*2 | *df* | *p* |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model 1 | 8.00 | 6,034.12 | 6,087.95 | -3,009.06 | 6,018.12 | NA | NA | NA |
| Model 4 | 10.00 | 6,017.25 | 6,084.53 | -2,998.63 | 5,997.25 | 20.87 | 2.00 | 0.00 |

Table 11:

*Model 5, addition of parental education (SES)*

|  | Estimate | 95% CI |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fixed effects** |  |  |  |  |  |
| Intercept | 0.69 | [0.55, 0.83] | 9.73 | 29.56 | < .001 |
| Time (Linear) | 0.29 | [0.14, 0.43] | 3.85 | 29.47 | .001 |
| Time (Quadratic) | -0.27 | [-0.31, -0.23] | -12.41 | 29.06 | < .001 |
| Trial type | -0.20 | [-0.28, -0.12] | -4.75 | 6,106.01 | < .001 |
| Parental education | 0.00 | [0.00, 0.01] | 0.94 | 29.48 | .355 |
| Testing location x Parental education | 0.01 | [0.01, 0.02] | 4.04 | 6,103.72 | < .001 |
| **Random effects** |  | **Variance** |  |  |  |
| Participant | Intercept | 0.008 |  |  |  |
|  | Time (Linear) | 0.155 |  |  |  |
|  | Time (Quadratic) | 0.002 |  |  |  |

*Note.* Equation = *proportion looking time ~ [time (linear) + time (quadratic)] + trial type + parental education + testing location x parental education + ([time (linear) + time (quadratic)] || participant)*

Table 12:

*ANOVA comparison of Model 5 to Model 1*

| Model | Number of parameters | AIC | BIC | Log-likelihood | Deviance | *X*2 | *df* | *p* |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model 1 | 8.00 | 6,034.12 | 6,087.95 | -3,009.06 | 6,018.12 | NA | NA | NA |
| Model 5 | 10.00 | 6,021.09 | 6,088.37 | -3,000.54 | 6,001.09 | 17.03 | 2.00 | 0.00 |

Table 13:

*Model 6, addition of vocabulary*

|  | Estimate | 95% CI |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Fixed effects** |  |  |  |  |  |
| Intercept | 0.676 | [0.6023,0.7497] | 17.98 | 28.68 | < .001 |
| Time (Linear) | 0.2619 | [0.1208,0.4031] | 3.64 | 28.35 | .001 |
| Time (Quadratic) | -0.2636 | [-0.3050,-0.2222] | -12.48 | 28.16 | < .001 |
| Trial type | -0.0497 | [-0.0960,-0.0034] | -2.1 | 5899.58 | .035 |
| Vocabulary | 0.0007 | [0.0001,0.0013] | 2.42 | 28.38 | .022 |
| Trial type x Vocabulary | 0.0002 | [-0.0002,0.0005] | 0.85 | 5896.3 | .396 |
| **Random effects** |  | **Variance** |  |  |  |
| Participant | Intercept | 0.007 |  |  |  |
|  | Time (Linear) | 0.138 |  |  |  |
|  | Time (Quadratic) | 0.001 |  |  |  |

*Note.* Equation = *proportion looking time [time (linear) + time (quadratic)] + trial type + vocabulary + testing location x vocabulary + ([time (linear) + time (quadratic)] || participant)*

Table 14:

*ANOVA comparison of Model 6 to Model 1*

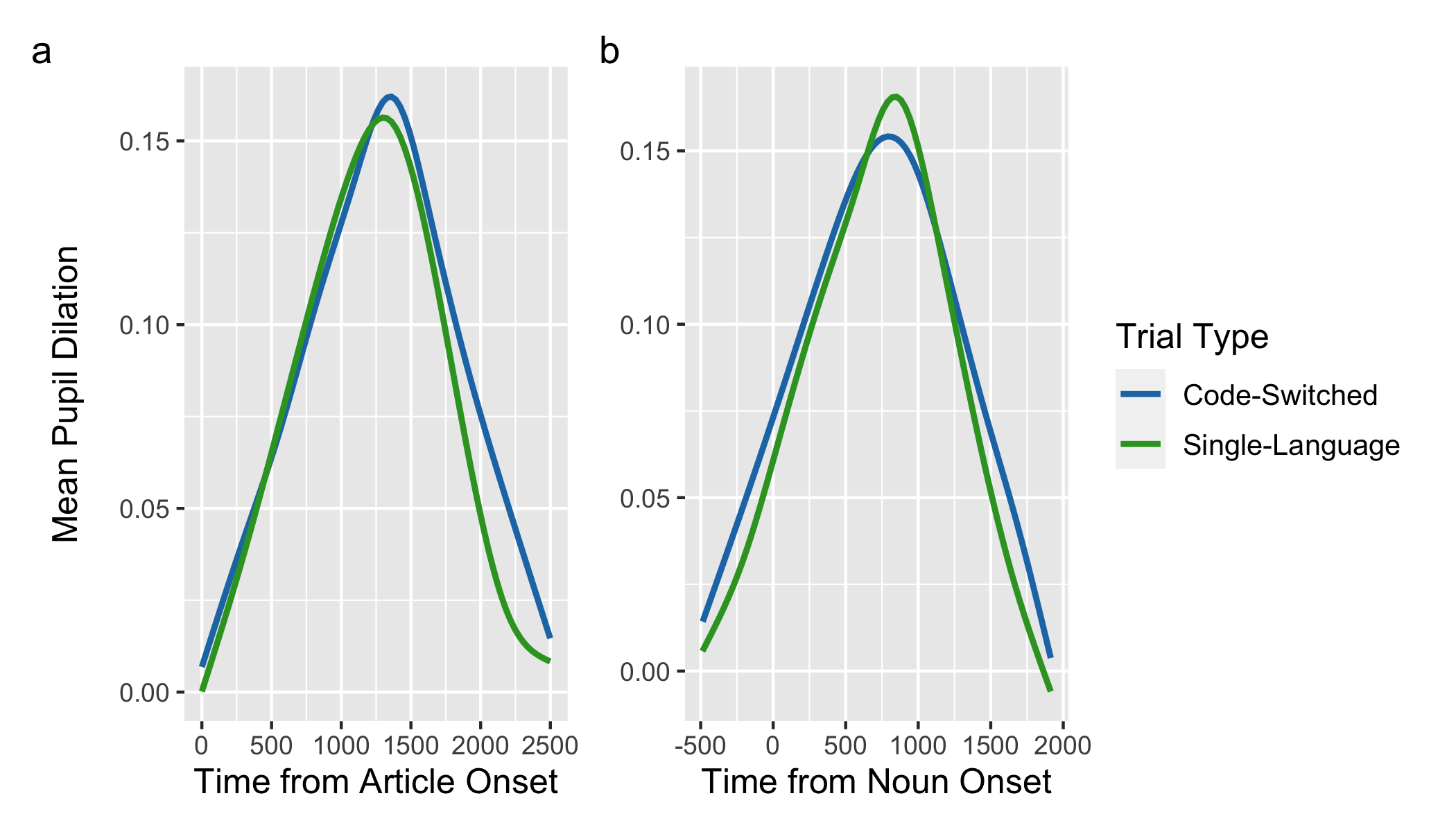
| Model | Number of parameters | AIC | BIC | Log-likelihood | Deviance | *X*2 | *df* | *p* |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model 1 | 8.00 | 5,863.09 | 5,916.64 | -2,923.55 | 5,847.09 | NA | NA | NA |
| Model 6 | 10.00 | 5,860.94 | 5,927.88 | -2,920.47 | 5,840.94 | 6.15 | 2.00 | 0.05 |

## Pupillometry

For the sample collected in Montreal, we were able to examine whether hearing a code-switched sentence elicits a processing cost via pupillometry, as the Tobii T60-XL eyetracker automatically records pupil size. Following the guidelines from Jackson and Sirois (2009), the data were pre-processed using the PupillometryR package (Forbes, 2020) in order to facilitate the analysis. The pre-processing began with regressing one pupil against the other. Because pupils often change size at a similar rate (Jackson & Sirois, 2009), this step allows data from one pupil to approximate the other when there is missing data. Then, the mean pupil size across both eyes was calculated in order to have a single pupil measure for each time sample. Data were then filtered with a moving hanning filter. The hanning filter calculates the pupil size through a weighted moving average to remove extreme values but keep the relevant effects (Kosie, 2019). Next, the data were baseline corrected by subtracting the average size of the pupil during the last 200ms of the carrier phrase before the first code-switch (e.g., 200ms before “*le bon*” in the sentence “Can you see *le bon* [fr. the good] duck?”). Baselining allows the change in pupil dilation within a window to be analyzed, as opposed to analyzing the raw pupil size which can drift over time. Trials were excluded from the pupillometry analyses if they were not analyzed in the looking time analysis (i.e., the child looked less than 750ms of the analysis window) or if they had no data during the baselining period or analysis windows. A total of 137 single-language trials and 120 code-switched trials were included in the following analyses (97% and 94% of single-language and code-switched trials included in the looking time analysis, respectively).

In order to isolate the effect of the code-switch from the carrier phrase to the article (e.g., Can you find *le bon* [fr. the good] …) and from the adjective to the noun (e.g., … *le bon* [fr. the good] duck?), we conducted separate analyses timelocking the data at the location of each code-switch. First, we examined pupil dilation for single-language and code-switched trials for 2000ms from the onset of the article. Across this time window, pupil dilation was similar between the two trial types, , , , 95% CI , indicating no differences in processing effort for the code-switched trials immediately after the first switch (See Figure 1a). Next, we examined pupil dilation for single- and code-switched trials for 2000ms after the onset of the noun in the stimulus. Across this time window, pupil dilation was similar between the two trial types, , , , 95% CI , suggesting no difference in processing effort for the code-switched trials when the language switched again at the noun (See Figure 1b).

Because articles began at different times across trials relative to the onset of the noun due to natural variation in speaking rate and length of the adjective (e.g., beautiful vs. old; *M* = 507ms, *Range*: 311 – 705ms), we extended the time window visualized in Figure 1a to match the analysis window of the switch to the noun, which lasted until approximately 500ms after the analysis window for the first switch. Similarly, in Figure 1b, we extended the window visualized to 500ms before the noun onset to approximately match the analysis window of the switch to the article.



*Figure* *1.*  Mean change in pupil dilation by trial type from (a) article onset and (b) noun onset. We encourage the reader to interpret this figure with caution as the onsets of the nouns (in a) and onsets of articles (in b) do not all occur at the same time on this visualization.

# References

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