Task-evoked pupil response for accurately-recognized accented speech

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Abstract

Unfamiliar second-language (L2) accents present a common challenge to speech understanding. However, the extent to which *accurately-recognized* unfamiliar L2-accented speech imposes a greater cognitive load than native speech remains unclear. The current study used pupillometry to assess cognitive load for native English listeners during the perception of intelligible Mandarin Chinese-accented English and American-accented English. Results showed greater pupil response (indicating greater cognitive load) for the unfamiliar L2-accented speech. These findings indicate that the mismatches between unfamiliar L2-accented speech and native listeners' linguistic representations impose greater cognitive load even when recognition accuracy is at ceiling.

Keywords: speech perception; accent; pupillometry

I. INTRODUCTION

Listening to unfamiliar second language- (L2-) accented speech is often described by listeners as an effortful process, even when L2 speakers are highly proficient (Munro & Derwing, 1995). Both L2- and regionally-accented speech are characterized by systematic segmental and suprasegmental deviations from standard native pronunciations of a given language or dialect. For example, when produced by nonnative Mandarin Chinese speakers of English, tense (e.g., /i/) and lax (e.g., /ɪ/) American English vowel pairs tend to be less phonetically distinct than when produced by native speakers (Wang & Heuven, 2006). Deviations such as these result in mismatches between L2 speech and native listeners' representations, which may cause reduced *recognition accuracy* (the proportion of words in the speech stream that can be correctly identified) and/or increased *cognitive load* (the degree to which cognitive resources are recruited at a given moment to meet processing demands; Pichora-Fuller et al., 2016). That is, resolving such mismatches may require additional cognitive resources not needed for native-accented speech (see Van Engen & Peelle, 2014, for an executive recruitment account of accented speech). Furthermore, even when unfamiliar L2-accented speech is accurately recognized, processing it should nonetheless require greater cognitive load than processing native speech.

Our research question was the following: Does unfamiliar L2-accented speech that is accurately recognized impose greater cognitive load than native speech? Behavioral studies have primarily relied on performance measures such as recognition accuracy (also referred to as “intelligibility”) and reaction time (e.g., processing speed for true vs. false sentence verification; Adank, Evans, Stuart-Smith, & Scott, 2009) to determine the costs of processing unfamiliar L2-accented speech. However, examining the cognitive load associated with the online processing of speech from highly proficient L2 speakers, including those whose speech can be accurately

1 recognized, requires a different methodological approach. To address our research question, we
 2 used pupillometry (the measure of pupil diameter over time) to examine cognitive load for native
 3 English listeners during the perception of accurately-recognized Mandarin Chinese-accented
 4 English and standard American-accented English. By using pupillometry in place of recognition
 5 accuracy and/or reaction time measures, we were able to examine the time-course of effortful
 6 processing for accurately-recognized speech. Notably, our definition of “recognition accuracy” is
 7 the proportion of keywords that the participant is able to correctly repeat, and does not
 8 necessarily reflect what the participant initially perceived; in fact, our hypothesis is predicated on
 9 the assumption that listeners are recruiting additional cognitive resources to re-process their
 10 initial perceptions. Further discussion of the mechanism(s) hypothesized to support this process
 11 are revisited in the discussion.

12 Pupillometry has been used for several decades as a non-intrusive, temporally-sensitive
 13 psychophysiological index of cognitive load (Beatty, 1982), and more recently has been applied
 14 within the domain of speech perception (for a review, see Van Engen & McLaughlin, 2018). Of
 15 interest for cognitive research is the task-evoked pupil response (from here forward simply *pupil*
 16 *response*), which is a phasic increase of pupil diameter linked temporally to a specific cognitive
 17 event (Beatty, 1982). These increases in pupil diameter are much smaller than changes due to
 18 luminance, and are related to up-regulation of sympathetic, and inhibition of parasympathetic,
 19 activity (Steinhauer, Siegle, Condray, & Pless, 2004; Beatty & Lucero-Wagoner, 2000;
 20 Peysakhovich, Vachon, & Dehais, 2017). Larger pupil response during a cognitive task indicates
 21 greater cognitive load. For example, Beatty (1982) found that pupil response was systematically
 22 larger for longer digit spans during a recall task.

Using acoustically degraded speech, it has been demonstrated that the pupil response increases systematically as speech becomes less intelligible (Zekveld, Kramer, & Festen, 2010; Zekveld & Kramer, 2014). Additionally, for Dutch-English bilingual listeners, pupil response for 50% intelligible English (i.e., L2) speech is greater when presented in English babble than in Dutch babble, and is greater when the speaker's language is not known in advance (i.e., when trials are randomized as opposed to blocked; Francis, Tigchelaar, Zhang, & Zekveld, 2018). Porretta and Tucker (2019) examined the effect of intelligibility using L2-accented speech, demonstrating for isolated words that there is greater and more sustained pupil response for unintelligible accented speech than intelligible accented speech. However, the potential difference in pupil response for accurately recognized, unfamiliar L2-accented speech and native speech remains to be investigated.

In a study using noise-vocoded speech, Winn, Edwards, and Litovsky (2015) found that even when analyses were limited to accurately-perceived trials, there was a systematic increase in pupil response as the spectral quality of the speech signal decreased. Thus, pupillometry is capable of capturing cognitive load as a function of recognition accuracy, but also revealing more nuanced differences in cognitive load when recognition is at ceiling. The latter makes pupillometry a valuable method for addressing our research question, and offers a novel way to quantify the challenge posed by accented speech.

In the present study, we measured pupil response during listening to speech from a native, standard American-accented speaker of English and a nonnative, Mandarin Chinese-accented speaker of English. We predicted that growth curve analysis (Mirman, 2014) of the pupil response would show an effect of speaker type (i.e., overall pupil diameter would be greater for the L2-accented speaker condition), and an interaction between speaker type and the

linear time term (i.e., indicating a difference in the rate of change of pupil diameter between conditions), reflecting greater cognitive load for processing L2-accented speech than native speech. Additionally, we predicted that subjective ratings of listening effort would be greater for the L2-accented speaker condition. Study preregistration is available at: <https://osf.io/bgcx7/>; all analysis scripts and data are available at: <https://osf.io/7dajv/files/>.

II. METHODS

1. Participants

Participants were young adults ($N = 52$, ages 18-22, 39 female and 13 male) recruited from Washington University's Psychology Subjects Pool. Hearing thresholds were measured for each participant to confirm they had clinically normal hearing. An additional 11 subjects participated and were excluded and replaced due to data loss either from equipment malfunction, or because they were not native speakers of American English, had parents who were not native speakers of American English, or had extensive exposure to Mandarin Chinese.

2. Stimuli

Sentence recordings of a native speaker of standard American English and a Mandarin-Chinese accented speaker of English were taken from Van Engen, Chandrasekaran, and Smiljanic (2012). All sentences were six words long, with four keywords (e.g., “the *gray mouse ate the cheese*”). Results from a pilot study (see Supplemental Materials) indicated that the Mandarin Chinese-accented stimuli had high recognition accuracy but were also rated as more accented and more effortful to understand than the native-accented stimuli. Root mean squared amplitudes for all stimuli were equalized using Praat (Boersma & Weenink, 2019). To control for natural differences in speaking rate, which is crucial for interpreting the time-course of the pupil response, the native speaker files were acoustically lengthened. Adjustments were made using

the Stretch function in Adobe Audition CC, which can adjust file lengths while controlling for pitch and speech characteristics. Files were lengthened by a constant amount, so that the average length of the native speaker files would equal the average length of the L2 speaker files. The L2 speaker files were not altered. A pilot experiment with unprocessed native stimuli is reported in the Supplemental Materials. The same pattern of results was found.

3. Procedure

Participants provided written informed consent prior to participation in the study. Following the consent process, they completed language and demographic questionnaires and underwent audiometric testing. Puretone thresholds at 500Hz, 1000Hz, and 2000Hz were used to establish a pure-tone average (PTA) for each participant. All participants had PTAs at or below 10dB in at least one ear.

For the pupillometry task, participants were seated in a sound-attenuating room facing a monitor and EyeLink 1000 Plus camera. All equipment was positioned following EyeLink specifications. During the experiment, participants rested their chins on a head-mount. They were instructed to fixate on a cross located in the center of the screen at all times. Two colors, red and blue, were used as cues for the participants. Whenever the cross was red, participants were instructed to reduce their blinking comfortably (if possible), while still prioritizing the listening task. Whenever the cross was blue, they were instructed to blink freely. Each stimulus was preceded by a baseline period (used during analysis to establish pupil size prior to input) with 3000ms of silence and a red cross. During the stimulus the cross remained red, and after the stimulus there was a delay period with 3000ms of silence and a (continued) red cross. After the recording window, the color of the cross changed to blue, and participants were instructed to repeat what they heard aloud. An audio recorder was used to record their responses. After the

participant clicked the spacebar to initiate a new trial, there was a final 3000ms silent delay with a blue cross to allow the pupil response to recover.

Sixty stimuli (30 per condition) were presented in a randomized order.¹ For subjective ratings of listening effort, participants were probed every three trials about the last sentence they had listened to and used the keyboard to respond, resulting in approximately 10 responses per condition. Participants responded using a scale of 1 to 9 where: 1 = “not effortful”, 5 = “moderately effortful”, and 9 = “extremely effortful.” All participants were debriefed after the experiment.

III. ANALYSES

1. Subjective Responses

For each participant, there were approximately ten responses to the effort probes for each speaker. Their mean was used as a composite rating score. Quantile-quantile plots of the scores demonstrated that they were not normally distributed, so Wilcoxon rank-sum tests were used to compare ratings for the two speakers.

2. Pupil Data Maintenance

Recognition accuracy was scored by a single researcher, and trials in which any keywords were missed were excluded from the pupillometry analyses (2.1% of total trials). A custom script written in R was used to manage pupil data.² This maintenance pipeline began by aligning data from each trial at sentence onset, and then averaging the pupil diameter during the 500ms preceding each target sentence to determine a baseline value for each trial. Timepoints with

¹ A pilot experiment with a blocked design is reported in the Supplemental Materials. The main effect of accent is present in both designs.

² All pupil diameter measures are reported in the unit of measurement automatically provided by the EyeLink 1000 Plus system, called “arbitrary units.”

missing data due to blinks were omitted when calculating the baseline value, and trials with fewer than 50% valid points during this window were omitted. Next, these baseline values were subtracted from pupil diameter throughout the rest of each trial to create a measure of absolute change. To remove effects of blinking, intervals of missing values were identified and then expanded to remove noisy readings caused by the eyelids moving prior to (by 30ms) and following (by 160ms) blinks (Winn et al., 2015; Zekveld et al. 2010). This expanded blink interval was then interpolated across using linear approximation. Lastly, the pupil data was smoothed using a 10Hz moving average (Winn, Wendt, Koelewijn, & Kuchinsky, 2018). Trials that required more than 50% interpolation were excluded from analyses. Across all participants and trials, 2.9% of timepoints were identified as blinks and interpolated. Across participants, less than one trial was excluded on average for this reason, and no participant exceeded 20% trial loss.

4. Growth Curve Analysis

Growth curve analysis (GCA) was used to model the pupil data in R (version 3.5.1) using the lme4 package. GCA is similar to polynomial regression, but controls for potential collinearity issues by orthogonalizing the polynomial time terms (Mirman, 2014). For the present study, we opted to use GCA instead of more traditional mean pupil diameter and peak pupil diameter measures for the following reasons: 1) GCA allows for analysis of the full shape of the pupil response, and analysis of all data in the time-course without averaging across trials (as is necessary with ANOVA); 2) calculation of the peak pupil diameter from pupil data averages (i.e., averages across trials within a given subject) can introduce noise into the analysis process; and 3) tests of mean pupil diameter are still present in GCA models (for our model, the main effect of condition), and peak pupil diameter can be indirectly tested by examining the slope and

shape of a given GCA model. The window of data used for model fitting began at 500ms after the stimuli began (based on visual inspection of the data) and ended 1000ms after the average sentence offset time (3344ms). The pupil data was time-binned, reducing the sampling rate from 500Hz to 50Hz. Table I shows the full model and its specifications. The time-course of pupillary response was modeled up to the third-order (cubic) orthogonal polynomial, based on hierarchical model comparisons that indicated significant contributions of the quadratic ($\chi^2_1 = 61.19$; $p < 0.001$) and cubic ($\chi^2_1 = 5.84$; $p = 0.016$) polynomials to model fit. For the speaker condition manipulation, dummy coding specified the native speaker as the reference (i.e., zero) group. The random effects structure included random intercepts and slopes for subject and item. Correlations between these slopes and intercepts were included in the random effects (as recommended by Mirman, 2014).

IV. RESULTS

1. Pupillometry

The summary output from the full model is reported in Table I, and the model fit is shown in Figure 1B. We predicted that there would be greater overall pupil response and a steeper increase of pupil response for the L2 speaker condition than the native speaker condition, resulting in a higher peak pupil response. The results confirmed both of these predictions, with a significant main effect of condition ($\beta = 59.40$, $SE = 10.75$, $p < 0.001$) and a significant interaction between the linear polynomial term and condition ($\beta = 1061.73$, $SE = 121.17$, $p < 0.001$). The interactions between condition and the quadratic and cubic terms were not significant ($\beta = -14.24$, $SE = 86.48$, $p = 0.870$; and, $\beta = 51.40$, $SE = 47.37$, $p = 0.282$, respectively), indicating that the shape of the pupil response for each condition was similar. Overall, the pattern of results in the full

- 1 model clearly demonstrate larger pupil response—and, thus, greater cognitive load—for
- 2 unfamiliar L2-accented speech.

Fig. 1. A) Subjective ratings of listening effort are shown using a combination of box-and-whisker and violin plots. The response scale went from 1 to 9, where: 1 = “not effortful”, 5 = “moderately effortful”, and 9 = “extremely effortful.” B) Pupil diameter over time is plotted as a function of speaker. Points and ribbons are used to represent the raw data means and standard errors, and model fit is overlaid with black lines. Onset time of all sentences is represented as a solid vertical line, and the average sentence offset time (i.e., 2344ms) for both conditions is shown as a dashed vertical line. The gray box indicates the area of interest used for modeling the pupil response. Pupil diameter is measured in “arbitrary units” on the y-axis, which are the units automatically provided by the EyeLink 1000 Plus system.

2. Subjective Responses

As shown in Figure 1A, the L2 speaker was rated as more effortful to understand than the native speaker ($p < 0.001$, 95% CI = [-2.03, -1.31]).

IV. DISCUSSION

The results of the current study indicate that processing accurately-recognized, unfamiliar L2-accented speech imposes greater cognitive load than native speech. These findings are consistent with an executive recruitment account for accented speech, under which we would predict that mismatches between the speech patterns of a speaker and a listener’s representations will require more cognitive resources to process—even when recognition accuracy is at ceiling. The

pupillometry data thus provides a novel and more nuanced account of unfamiliar accented speech processing, capturing differences in effort that standard measures of recognition accuracy (i.e., “intelligibility”) cannot. The one way in which recognition accuracy measures have been used to study highly intelligible speech is by presenting the speech in noise (to bring intelligibility off ceiling). Pupillometry has the distinct advantage of not requiring acoustic signal degradation. However, the limitations of the study design should also be noted. Most importantly, the current study uses a single talker in each condition, so it will be important to verify that these results can be replicated with other types of unfamiliar accented speech. Future work could expand upon these results by measuring pupil response for multiple speakers of a given accent, and for multiple types of unfamiliar nonnative accents and regional dialects.

Our findings also indicate that listeners are aware that processing unfamiliar L2-accented speech is more cognitively demanding than processing native speech. Complementing the pupillometric findings, participants also rated the highly proficient L2 speaker as significantly more effortful to understand than the native speaker (see also Munro & Derwing, 1995). However, while these subjective ratings match the physiological evidence, it is also possible that they reflect participants’ expectations and/or biases regarding accented speech, and not their awareness of increased cognitive load. That is, participants may have rated the unfamiliar L2-accented trials as more effortful because accented speech is stereotypically more difficult to understand than native speech.

Investigating the executive function(s) underlying the increased cognitive load for unfamiliar L2-accented speech will also be an important direction for future research. Current speech perception models, such as the Ease of Language Understanding model (ELU; Rönnberg, Rudner, Foo, & Lunner, 2008; Rönnberg, et al., 2013), propose a dual role of working memory

1 during speech perception, emphasizing that it is important both for storage of the unfolding
2 speech stream and for top-down processing of phonetic and semantic ambiguity. In line with this
3 model, the current literature suggests that working memory may be particularly important for
4 resolving perceptual ambiguities in unfamiliar accented speech. Both McLaughlin, Baese-Berk,
5 Bent, Borrie, and Van Engen (2018) and Janse and Adank (2012) found that working memory
6 capacity is positively related to recognition accuracy for accented speech in young and older
7 adults, respectively. While the ELU model primarily focuses on acoustically degraded speech,
8 the current findings motivate exploration of how individual differences in working memory may
9 play a critical role in unfamiliar accent processing, and, possibly, be reflected in pupil response
10 during listening.

11 In summary, our findings indicate that processing unfamiliar L2-accented speech imposes
12 greater cognitive load than processing native speech, as evidenced by a larger and more rapid
13 pupil response. Most notably, recognition accuracy for the unfamiliar L2-accented speech stimuli
14 used in the current study was at ceiling, indicating that mismatches between the speech patterns
15 of L2-accented speech and native listeners' representations require greater support from
16 executive resources (such as working memory) to reconcile. Additionally, while the accented
17 stimuli in the present study were recordings of a Mandarin-Chinese accented speaker of
18 American English, we would predict these findings to replicate with other unfamiliar L2 and
19 regional accents as well. If—as we have proposed—increased cognitive load stems from the
20 mismatches between the speech patterns of a speaker and a listener's linguistic representations,
21 then there should be greater pupil response for other unfamiliar accent types as well. Testing the
22 boundaries of this prediction will be an important next step for this area of inquiry.

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1 Tables

2 TABLE I

3

4 Growth curve analysis model code and summary output. “ot1”, “ot2”, and “ot3” refer to the
 5 linear, quadratic, and cubic polynomial time terms, respectively. Data was dummy coded such
 6 that the native speaker condition was the “Intercept” term.

R Code:

```
lmer(Diameter ~ (ot1+ot2+ot3)*Condition + # fixed effects
      (1 + ot1 + ot2 + ot3 | Subject) + # random effects
      (1 + ot1 + ot2 + ot3 | Item), # random effects
      data = PRA_E2R_TB50_AOI.df)
```

Term	Estimate	SE	DF	<i>t</i>	<i>p</i>
Intercept (Native)	180.73	16.30	77.31	11.085	< 0.001 ***
ot1	1061.73	121.17	77.89	8.763	< 0.001 ***
ot2	-596.76	87.84	102.36	-6.793	< 0.001 ***
ot3	-118.10	44.58	96.16	-2.649	0.009 **
Condition (Nonnative)	59.85	10.75	58.14	5.565	< 0.001 ***
ot1:Condition (Nonnative)	453.50	83.53	58.02	5.429	< 0.001 ***
ot2:Condition (Nonnative)	-14.24	86.48	58.41	-0.165	0.870
ot3:Condition (Nonnative)	51.40	47.37	58.08	1.085	0.282

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8

Supplemental Materials

I. PILOT EXPERIMENT

A. Overview

In the main experiment, we controlled for systematic differences in the speaking rates of the native English speaker and the Mandarin-accented speaker by lengthening the native stimuli. Here, we report the results of a pilot experiment in which we presented the stimuli without any manipulation. The predictions were the same as the experiment reported in the main text: the overall mean pupil diameter and the rate of change of pupil diameter would be greater for the L2-accented speaker than the native-accented speaker, and the L2-accented speaker would be subjectively rated as more effortful to understand than the native speaker. An additional rating measure was included to assess how accented the speakers were each perceived to be as a manipulation check to confirm that the L2 speaker was perceived as accented. All data files and stimuli are available at: <https://osf.io/7dajv/files/>.

B. Methods

1. Participants

Young adult participants ($N = 30$, 20 female and 10 male, ages 18-27) were recruited from Washington University's Psychology Subjects Pool. Eight additional participants were excluded and replaced because of data loss and/or equipment malfunction, or reports that they were not native speakers of American English, had parents who were not native speakers of American English, or had extensive exposure to Mandarin Chinese. Pure tone audiometry was administered for each participant to confirm that they had normal hearing. Participants were compensated with class credit.

2. Stimuli

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Stimuli were the same as those used in the main experiment; however, for the pilot experiment the recordings of the native speaker were not lengthened. Thus, the recordings for both speakers were natural, and the Mandarin-accented stimuli were generally longer.

3. Procedure

The procedure matched the main experiment with the following exceptions: stimuli were blocked by speaker, such that the main section was comprised of four blocks that alternated between speaker type (i.e., 15 stimuli each). Blocking was counterbalanced across subjects. After each block, participants were asked to rate the speaker on a scale of 1 to 9 for how effortful they were to understand (where 1 = “not effortful”, 5 = “moderately effortful”, and 9 = “extremely effortful”) and how accented they sounded (where 1 = “native English speaker”, 5 = “moderately accented”, and 9 = “extremely accented”). Verbal responses were recorded by a researcher in the room and a recording device. The timing of the trial-by-trial design also differed slightly: each stimulus was preceded by a 2000ms quiet baseline period and followed by a 2000ms delay period, during which the cross was red. After the red recording period, the color of the cross changed to green, cuing the participant to repeat what they heard aloud. Colors were changed to red and blue in the main experiment to accommodate participants with color blindness.

C. Analysis

The same custom R script was used to manage pupil data for the main experiment and the pilot experiment. The only difference when processing the pilot data was that the pipeline began by aligning data from each trial at sentence offset, with the intent of aligning the peak responses across trials regardless of stimuli length (Klingner, Tversky, & Hanrahan, 2011). Across all participants and trials, 2.4% of timepoints were identified as blinks and interpolated across. The

window for analysis began at average onset time of the accented trials (-2327ms) and ended 1000ms after sentence offset time.

D. Results

1. Pupil Data

Supplemental Table II contains output from the full model, and Supplemental Figure 2 shows the raw data with the model fit overlaid. The largest random effect structure that would converge included random intercepts and slopes for the subject-by-condition term on each of the orthogonal polynomial terms. This random effect structure captures individual differences in the effect of the condition manipulation on each subject (p.68, Mirman, 2014), and, thus, should capture more variance than the subject random effect would alone. In comparing models, we found the model reported in Table I to be the most conservative.

Supp. Fig. 2. Data from the pilot experiment show larger pupil response for L2-accented than native speech. Raw data means and standard errors are represented as points and ribbons, and model fit is overlaid with black lines. The solid vertical line represents the aligned offset time for all sentences, and the two dashed vertical lines represent average sentence onset times for the native (rightmost) and L2-accented (leftmost) conditions. The gray box indicates the selected

area of interest used for modeling the pupil response. Pupil diameter is measured in arbitrary units on the y-axis.

As predicted, there was a significant effect of condition ($\beta = 75.51$, $SE = 29.62$, $p = 0.013$), reflecting greater mean pupil diameter for the L2 speaker condition than the native speaker condition. The interactions between condition and the linear and cubic terms were also significant ($\beta = 1,109.12$, $SE = 351.68$, $p = 0.003$; and, $\beta = 982.81$, $SE = 205.09$, $p < 0.001$, respectively). The interaction with the linear term—while consistent with our hypotheses—is likely attributable to the systematic difference in stimuli length between the two conditions (i.e., the L2 speech was slower), and not due to a difference in the rate at which pupil diameter increased. Additionally, the interaction between condition and the cubic term appears to be present due to the alignment of the two conditions, and not for theoretically notable reasons (i.e., two inflection points of the native curve, and only one of the L2 curve, are captured in the analysis window; Supplemental Figure 2). Thus, the systematic difference in stimuli length complicated the interpretation of the results and motivated the editing of the native speaker files for the main experiment.

2. Subjective Responses

Results of Wilcoxon rank-sum tests found that the L2 speaker was rated as more effortful to understand than the native speaker ($p < 0.001$, 95% CI = [-3.00, -2.00]), and as sounding more accented ($p < 0.001$, 95% CI = [-4.50, -3.75]).

E. Brief Conclusion

Moving forward, we recommend that researchers investigating speaker differences using pupillometry carefully control for stimuli length between conditions. While the primary result of the present study remained the same between the pilot and the main experiment (i.e., the

PUPIL RESPONSE FOR ACCENTED SPEECH

- 1 differences in mean and peak pupil diameter), the interpretation of the shape of the pupil curve
- 2 was largely affected.

Tables

SUPPLEMENTAL TABLE I

Growth curve model code and summary output from Experiment 1. “ot1”, “ot2”, and “ot3” refer to the linear, quadratic, and cubic polynomial time terms, respectively. Data was dummy coded such that the native speaker condition was the “Intercept” term.

R Code:

```
lmer(Diameter ~ (ot1+ot2+ot3)*Condition + # fixed effects
      (1 + ot1 + ot2 + ot3) | Subject:Condition), # random effects
data = PRA_E1_TB50_AOI.df)
```

Term	Estimate	SE	DF	<i>t</i>	<i>p</i>
Intercept (Native)	78.14	20.95	57.98	3.731	< 0.001 ***
ot1	92.50	248.68	58.03	0.372	0.711
ot2	-924.45	220.37	57.90	-4.195	< 0.001 ***
ot3	-1299.26	145.03	57.98	-8.959	< 0.001 ***
Condition (Nonnative)	75.51	29.62	57.98	2.549	0.013 *
ot1:Condition (Nonnative)	1109.12	351.68	58.03	3.154	0.003 **
ot2:Condition (Nonnative)	-168.05	311.64	57.90	-0.539	0.592
ot3:Condition (Nonnative)	982.81	205.09	57.97	4.792	< 0.001 ***