A First Examination of Aphasia Using Pupillometry

Advances in technology have allowed the measurement of sentence processing to move from off-line analyses (where conscious reflection and problem-solving form part of the measureable output) to on-line analyses. In the present study we add to the quiver of on-line methods by revisiting an old technique, pupillometry. The magnitude of pupil dilation is a function of the processing load required to perform a task (Beatty, 1982; for a complete history of pupillometry see Hess, 1975 and Andreassi, 2007), including short-term memory load (Kahnemann & Beatty, 1966). More recently, pupillometry has been used to measure the processing load that results from syntactic complexity (Just & Carpenter 1993; Piquado et al., 2010) and the resolution of syntactic ambiguity by prosody and context (Engelhardt et al., 2009). These efforts have averaged pupil responses across relatively large time windows, from 1 second to several seconds post-target. More recently, we examined pupil dilations every 17ms and found that the time-course of dilations differed depending on the type of grammatical violation. We continued with that effort and crossed grammaticality with plausibility. We found that pupil diameter increased approximately 200ms earlier for a morphosyntactic violation than for a plausibility manipulation, suggesting some support for a syntactic (re)analysis that has an earlier time-course than plausibility information.

In the present study we move to examine on-line pupillometry with participants who have aphasia, perhaps the first effort to do so. There are several advantages to pupillometry. It has high temporal sensitivity, equal to, for example, event-related electrophysiology (ERPS); it offers a continuous measure of processing load without requiring an explicit secondary task; it appears to be sensitive to a myriad of experimental manipulations that affect workload or processing load; and it is very participant-friendly. In this first effort examining aphasia, essentially a proof-of-concept, we manipulate the thematic fit that occurs between a verb and its arguments. Consider the following examples:

1. The creative artist sketched a portrait# during the gallery's reception.
2. The creative artist chewed a portrait# during the gallery's reception.

In (1) the verb *sketch* occurs with a subject (*creative artist*) and object (*portrait*) that fit its thematic requirements (that is, the verb *sketch* needs arguments that can 'sketch' and 'be sketched'). In (2) however, the verb *chew* occurs with the same arguments that occur with *sketch* in (1), and thus they do not fit the thematic requirements of the verb. The inception point at which the two are differentiated via their plausibility is indicated by #. There have been several psycholinguistic studies that have examined the effect of thematic fit on comprehension in healthy college-age participants (Stowe, 1989; McElree & Griffith, 1995; Garnsey et al., 1996; McRae et al., 1997; Mc Rae, Spivey-Knowlton & Tanenhaus, 1998), and most have shown an increase in processing load. Thus we assumed that this contrast would be a reasonable test of the sensitivity of pupillometry.

Participants:

In this abstract we present data from two persons with aphasia (PWA) (Ages: 49 years and 36 years) who both fit a Broca's aphasic profile and have Boston Diagnostic Exam scores of 2, and 3, respectively, though we are actively running several more (and these data should be available if we present at CAC). They were compared to two age matched controls (AMC).

Table 1:

Patient	Date of Birth	Date of Stroke	Years of Education	BDAE Severity	WAB AQ
LHD009	3/16/1961	8/25/2001	17	3	76.3

LHD140	6/11/1975	12/2000	16	2	72.9

Design:

The experiment is a two session, within-subjects, minimal pairs design; participants received all stimuli from all conditions across the two sessions.

Participants were asked to “Focus on the cross in the middle of the screen and listen to the sentences for content.” The cross would then appear, followed by 750ms of silence to allow the pupils to acclimate. Then a sentence would play and end with another 750ms of silence. Twenty percent of all sentences were followed by a “Yes/No” content question. Each session was broken into four blocks lasting about six minutes each. Each session lasted approximately 40 minutes and contained 30 plausibility sentences and 30 gapping sentences.

A 1500ms region of interest was defined, which included the 1500ms that followed the inception point, defined as the point at which the sentences become probable/improbable - immediately after the direct object. The inception point in the speech stream was checked by three raters: if the raters disagreed by more than plus or minus 17ms, the sentences were reexamined until agreement was reached.

Analysis:

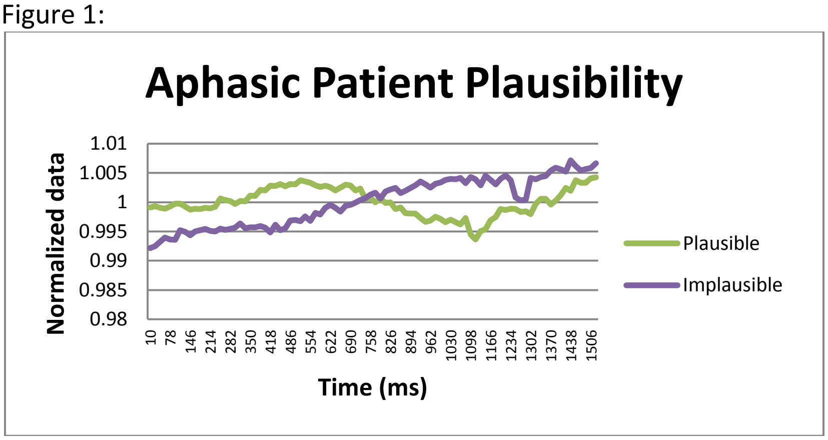
To generate a mean pupillary response while processing the sentences, the mean pupil diameter was calculated by averaging all of the pupil diameter measurements in the 1500ms time window of observation for each condition. This average pupil diameter was used as a sentence processing baseline. The dependent measure, normalized pupil data, was calculated by dividing each data point in the 1500ms time window for each condition by the baseline for that condition. This is the similar to the normalization process used in Engelhardt et al. (2009).

Once the data were normalized, scores were averaged across each time point for all participants in each condition.

Results and discussion:

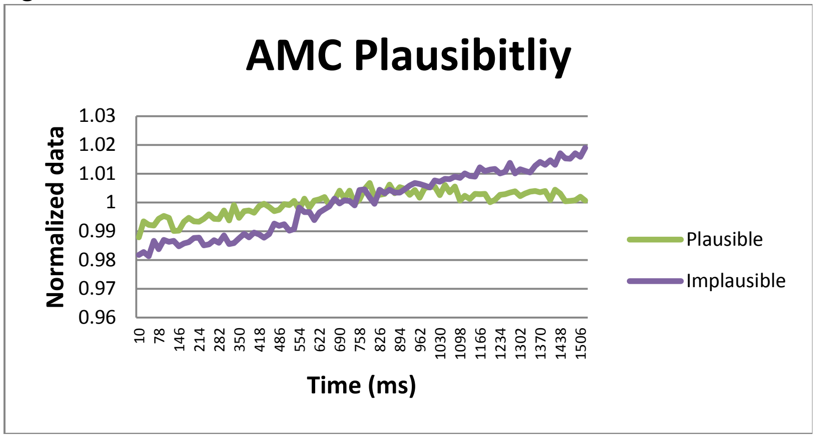
The following graphs are the waveforms for the plausible (1a) and implausible (1b) conditions for both the PWA and the AMCs. The graphs begin at the inception point and show the normalized pupil data for the next 1500ms.

Figure 1:



Time	t-test
0-250	<0.001
250-500	<0.001
500-750	<0.001
750-1000	<0.001
1000-1250	<0.001
1250-1500	<0.001

Figure 2:



Time	t-test
0-250	<0.001
250-500	<0.001
500-750	<0.001
750-1000	0.313
1000-1250	<0.001
1250-1500	<0.001

Both the AMC and PWA evinced an increase in processing loads in the implausible condition. For the PWA, the implausible condition elicited larger pupil dilations approximately 775ms after the inception point, while the AMC group showed the increase at approximately 1000ms after the inception point. Due to the low number of participants in this pilot work, it is difficult to draw conclusions based on the statistics.

Discussion:

The time course for pupillary response for our PWA in the current experiment is similar to findings we are observing in young adults in response to the same stimuli. Approximately 800ms after the inception point, the pupil diameters become significantly larger in the implausible condition and maintain this trend to the end of the 1500ms time window. We are not sure what to make of the later time-course for our AMCs at this point, and again caution about our minimal N. Even so, we have demonstrated that pupillometry can be used effectively with individuals who have aphasia. Furthermore, the continuous nature of pupillometric measurement allows us to generate processing load waveforms with high temporal resolution for examining the time-course of sentence processing in aphasia. The implications, we believe, are significant in that we can measure the moment-by-moment effects of grammatical variables, as well as variables that manipulate working memory load and resource capacity. We are currently testing several other contrasts, with additional participants, and hope to make these data available to the CAC community.