PASCAL: Pressure Analysis for Studying Cognition, Autonomic Function, and Language

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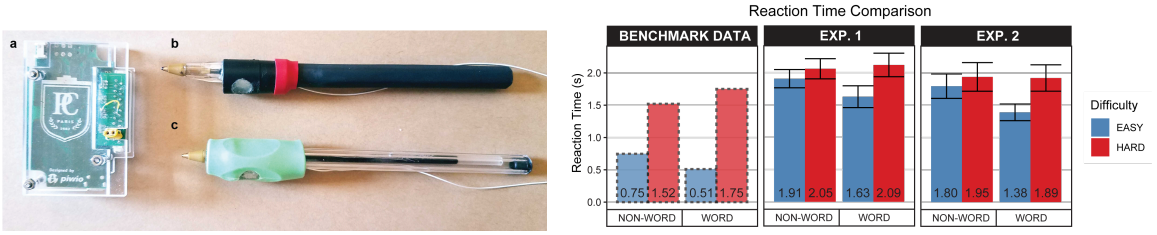
Tools such as electroencephalography, pupillometry, and skin conductivity measurement offer the potential to directly characterize the physiological correlates of cognitive load during language processing. Each of these methods possess unique advantages, but also shortcomings, be they cost, lack of portability, or the discomfort they induce in participants. Many shortcomings of these methods are amplified when applied to investigations that attempt to study cognition in naturalistic language tasks. For instance, written language production tasks are incompatible with increasingly popular measures of processing load that utilize pupillometry and skin conductivity paradigms, which limit freedom of movement of the head and hands. One way to extend the affordances of psycholinguistic research in such environments is to develop methods that allow for the extraction of markers of cognitive load directly from the intrinsic dynamics of task-relevant behaviors such as speech and handwriting.

We present PASCAL, a novel research instrument that is potentially useful for studying psycholinguistic phenomena, driven by the theory that cognitive load correlates with motor activity in handgrip and writing (Luria and Rosenblum, 2010; Van Gemmert and Van Galen, 1997; van Loon et al., 2001). We have developed a pen that can measure subtle changes in lateral muscle pressure exerted during handwriting. These measurements can be used to infer the cognitive load induced by language processing or task context. This pen utilizes recent advances in flexible capacitive sensors (Pruvost et al., 2019) to provide high-frequency (sr = 1kHz) recording of pressure in **absolute units (pascal)**, allowing for comparability of measures across individuals and populations. The capacitive sensors are lightweight and integrated into traditional pens (Fig.1), allowing naturalistic handwriting. To establish the utility of such a tool within the context of current psycholinguistic paradigms, we first present pilot **benchmarking replications** of classic chronometric findings in a lexical decision task, and then illustrate how continuous pressure measurements may provide additional insights into language processing.

In **Exp. 1**, 68 participants conduct an auditory lexical decision (LD) task. 24 high-frequency and 24 low-frequency words, as well as 48 nonwords with high or low transitional phoneme probability in English, were selected from a large database (Tucker et al., 2019). On a printed study sheet, participants write 'yes' or 'no' to indicate their LD, and spell each stimulus, while handgrip pressure is recorded. **Exp. 2** is identical in structure to Exp. 1 with the exception that participants fill in a multiple choice (yes/no) bubble sheet to make the LD, rather than writing out the words 'yes' or 'no', and giving participants 6 instead of 4 seconds to make their LD.

As widely reported for lexical decision tasks, we expect to see faster responses for high-frequency words relative to low-frequency words and high-probability non-words relative to low-probability non-words. We furthermore expect to see a differential in lateral pressure across both word/nonword and high-frequency/low-frequency conditions, in line with previous writing pressure literature. In both experiments, response onset is automatically detected as an increase over baseline handgrip pressure of 5 kPa. Pressure values are averaged during the LD period. Onset times and mean pressure across conditions are compared using maximal mixed effects models. Initial pilot data are consistent with our predictions (see Fig. 1b and Fig. 2).

By benchmarking our results to previous findings in these and other experimental paradigms, we will determine both external and construct validity of this method. This initial study demonstrates the promise of integrated pressure sensing in language comprehension research, but future studies will target more naturalistic free composition and text copying tasks which may afford a unique opportunity to study written language production, chart the progress of typical and atypical handwriting acquisition, and understand the role of effort, stress and fatigue in cognition.



(a) a. Microcontroller used to digitize signal. b-c. Two prototype pens used in Exps. 1 & 2.

(b) Benchmark lexical decision reaction times (left). Pilot lexical decision reaction times in Exp. 1 (Y/N; middle) and Exp. 2 (OMR; right).

Figure 1: Pen prototypes (a), and obtained reaction times (b) compared with benchmarks.

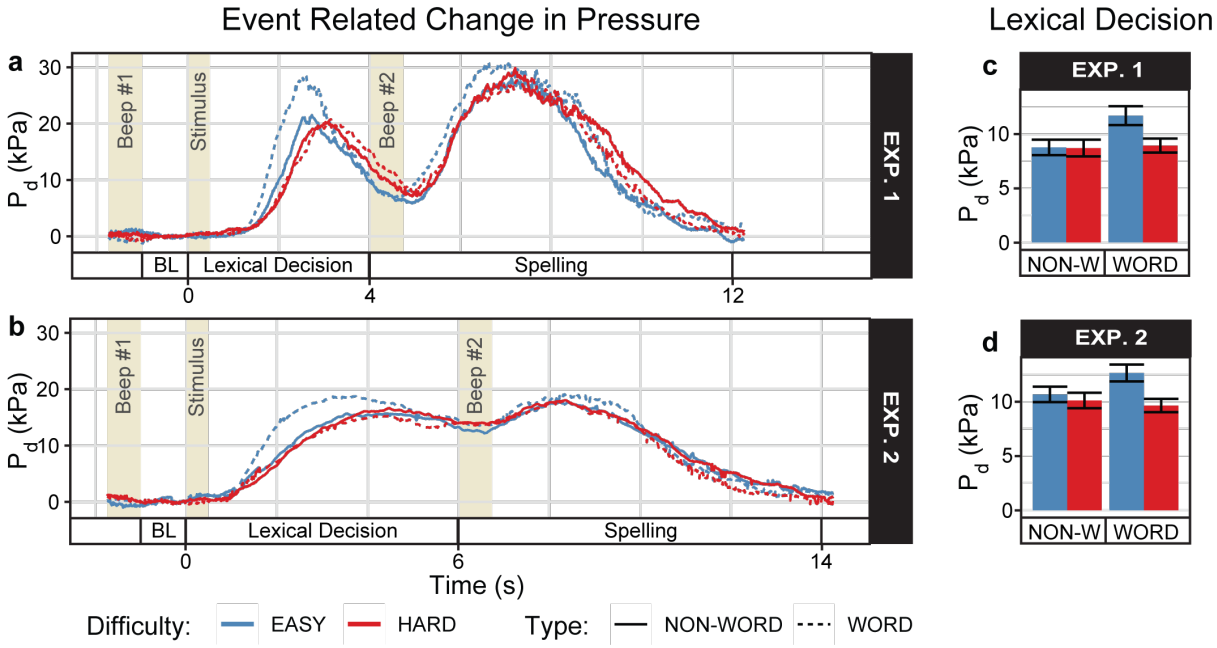


Figure 2: Event-related changes in pressure (P_d) during lexical decision tasks. In a and b, P_d for each condition averaged across participants in the handwritten Y/N task, and in the bubble task, respectively. The timescale is locked to the onset of the stimulus. In c and d, average mean P_d in the lexical decision period across all participants for each of the four conditions. Error bars are standard error.

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