Using microcontroller instrumentation to teach cognitive neurophysiology

M. JAYACHANDRA[1,2], A. PREMCHANDRA[1], N. HEBBAR[1], M. ARORA[3];

[1]St. John's Res. Inst., Karnataka, India; [2]Bioengineering Group, NDRF, Inst. of Engineers, Bangalore, India; [3]CPDM, Indian Inst. of Sci., Bangalore, India

It has been a challenge to teach graduate students experimental neurophysiology in resource-limited situations, given the prohibitive cost of commercial equipment. With the advent of micro-controllers with in-built sensors, e.g., *Arduino*, it is now possible to build robust, costeffective instrumentation to teach cognitive neurophysiology by demonstrating scalp-recorded auditory event-related potentials (ERPs), e.g., ABR, AEP, MMN, P50-gating, Auditory P300, etc. The vast amount of *Arduino* documentation, tutorials and sample code on the internet allows fast prototyping and deployment on this platform.

We have designed such an *Arduino*-based system where a synchronization trigger generates auditory clicks (0.1ms - 1ms), tones (100ms with 5ms on-off ramps to prevent edge effects), and broad-band white noise of varying lengths. Trigger and stimulus programming was done in the *Arduino* Integrated Development Environment (IDE) using its simple C language variant. Trigger jitter was 5ns and allowed the presentation of short click stimuli (0.1ms). The auditory stimuli were amplified with an off-the-shelf amplifier and the speaker/headphone output was adjusted to ~60dB using a *Brüel & Kjær* Type 2240 sound level meter.

For human recordings, this system was interfaced with bio-amplifiers *(Matsuzaka et al., JUNE, 10(2):A118-A124, 2012)*, and a 2-channel *Tektronix TBS-1000EDU* oscilloscope for A-to-D conversion and basic analysis. Scalp recordings from C_z and F_z were used to introduce students to electrophysiology and ERP concepts. The inexpensive *EDU* oscilloscope was found well suited for developing teaching courses for electrophysiological data analysis (latencies, peak measurements, area under the curve, FFT, etc.) and *Arduino* programming. Importantly, these courses can be shared on the internet.

This system can be extended to visual cognitive ERPs, e.g, VEP, P300, N400, Recognition Potential, etc., by presenting visual stimuli using a dedicated small-footprint PC and open-source software, e.g., *Raspberry PI* and *OpenSesame.*

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