# BCI Accuracy Using Classifier-Based Latency Estimation and the Optimal Interstimulus Interval

Tegan M. Brandt, Taylor Sweet, David E. Thompson, Ph.D

*Abstract*— **Purpose: Detection of event-related potentials (ERPs) in brain-computer interfaces (BCIs) allow for communication by individuals with neuromuscular disorders. Enhancing BCI accuracy may be possible through the exploration of the optimal interstimulus interval (ISI). Our objective is to investigate the relationship between BCI accuracy and the optimal ISI value for an individual.**

**Approach: Using the previously developed classifier-based latency estimation (CBLE) [1], we investigated the relationship between the interstimulus interval (ISI) and P3 Speller BCI accuracy. Participants underwent two consecutive sessions in one day. The first session had a default ISI value of 120ms. An optimal ISI value calculated from the first session was used in the second.**

**Results: Ten subjects participated in the study. Of the ten, half received an optimal ISI value of 120ms and half 160ms. Accuracy differences after implementing the adjusted ISI ranged from -26.1 percent to 4.35 percent. Suggestions for additional experimental design adjustments are highlighted under the discussion portion of this manuscript.**

## I. Introduction

The use of a brain-computer interface (BCI) can assist those with neuromuscular disorders by establishing or reestablishing communicative ability without the use of muscular action [2]. In the past couple decades, BCI research has produced promising results geared toward granting communication to individuals with ailments such as amyotrophic lateral sclerosis (ALS).

In 1988, Farwell and Donchin proposed a communication aid with the utilization of the P300 brain response. The P300 is an event-related brain potential (ERP) [3]. To date, the P3 Speller derived from the study is the most common type of BCI. A P300 wave is present when an individual actively engages in a target-seeking activity, provided the target is rare in comparison to non-target stimuli. After a target stimulus, a positive deflection occurs; its peak amplitude is found nominally at 300ms. The true latency of the deflection appears to correlate with an individual's age [4] and can vary significantly between individuals [5,6]. Additionally, ISI variation factors in individuals are attributed to time of day, food intake, and interest in activity stimulus [7].

In their seminal paper, Farwell and Donchin mentioned that variability in P300 latency would preclude good performance of the P3 Speller system. The Classifier-Based Latency Estimation (CBLE) method was designed to estimate P300 latency and has been shown to strongly predict BCI accuracy [1]. The technique is a generalization of the Woody and Nahvi method used to find optimal latency shift [8]. The CBLE technique takes advantage of classifier sensitivity to latency variability. CBLE works by applying the classifier at varying time shifts and searching for the maximum classifier score [1].

The interstimulus interval (ISI) is defined as the time between the end of one stimulus and the onset of the following stimulus. Optimizing ISI values entails finding the unique length in time between stimuli, which yields the best accuracy result for an individual. This optimal value is often correlated to the subject's age and cerebral function [9]. Therefore, the optimal ISI value for individuals is unique. However, most groups do not set individual ISIs, in part because the typical method for doing so would require considerable data collection (at a minimum, several characters at several different ISIs). This study focuses on a preliminary method based on CBLE from a small dataset to predict optimal ISI. The statistical variance of the CBLE is labeled as vCBLE and exhibits a high correlation with accuracy [1]. Participants with a high vCBLE have the potential to benefit from a larger ISI value, while those with a low vCBLE may be able to type faster with a lower ISI, without the risk of accuracy loss.

## II. Materials and Methods

### A. Equipment

All recordings were made using a 64-channel Mobile-72 wireless electroencephalogram (EEG) cap manufactured by Cognionics. The cap records from 64 individual channels placed according to the international 10-20 system, with reference and ground at the left and right mastoids. Data logging and stimulus presentation were handled by the BCI2000 software platform running on a Windows 7 laptop.

### B. Experimental Design

Each participant completed two consecutive sessions in one day, which avoids the day-to-day variability of ISI. The study utilized BCI2000's row-column ERP Speller. To familiarize the individual with the system, the five-character word 'JUMPS' was presented as an activity. 13 full sets of row-column intensifications were used as the stimuli. Each participant completed the test word once before continuing the study. The default ISI value was 120ms.

Each session was comprised of a 'train' and 'test' phrase. For the first session, a default ISI value of 120 was used. A 19-character phrase, 'THE QUICK BROWN FOX' was implemented as the train phrase and the 23-character phrase 'MY BIKE HAS A FLAT TIRE' was designated as the test. After the first session was completed, each participant's accuracy and optimal ISI value were calculated. The BCI2000 block size allowed for only three possible ISI values: 120ms, 160ms, and 200ms. For the second session, the same two sentences were used, but with the new ISI value. The intent was that the change in ISI value would yield a better accuracy during the second session.

### C. *Optimal ISI*

With the use of data collected from [1], linear regression was performed to model accuracy as a function of the square root of vCBLE. From the accuracy model, it was determined that 95 percent accuracy is expected from a participant with a square root vCBLE of 42ms. This value is one third of the 125ms ISI window used in the original study. In similar fashion, the optimal ISI value for each participant of this study was calculated as follows:

$$Optimal\ ISI = 3 * \sqrt{vCBLE}$$

The optimal ISI value, calculated from above, was then rounded to the nearest multiple of 40ms to fit the BCI2000 parameters.

### D. *Participant Demographics*

All activities were performed under Kansas State University Institutional Review Board approved protocol #8320. The data were collected from the first ten participants who successfully completed the sessions described above. Of the participants, six were female and four were male. Ages of the participants ranged from 21 to 65 (mean 33.7). The average male age was 28.8 and the average female age was 37 years respectively. All recruited participants were able-bodied individuals, one of which had previous BCI study experience. The remainder of the participants had never been exposed to BCI research.

### E. *Data Explanation*

The EEG data were collected using a 64-channel Cognionics EEG amplifier. To reduce the feature set and stay consist with the methods in [1], only 16 channels of the 64 were used and the signal was down sampled from 500 Hz to 16 Hz. These channels were F3, Fz, F4, T7, C3, Cz, C4, T8, CP3, CP4, P3, Pz, P4, PO7, Oz, and PO8 according to the international 10-20 system. Training was determined by setting epochs to average to the number of sequences within the application module. In this case, the value was 7.

## III. RESULTS

### A. *Accuracy*

As previously stated, the intent was the adjusted ISI value would lead to a higher accuracy during the second session. Of the ten participants, two performed at a higher accuracy during the second session, five participants had the same accuracy value, and three showed a less accurate response. The average accuracy of the first and second sessions were 87 percent and 83 percent. (See Figure 1).

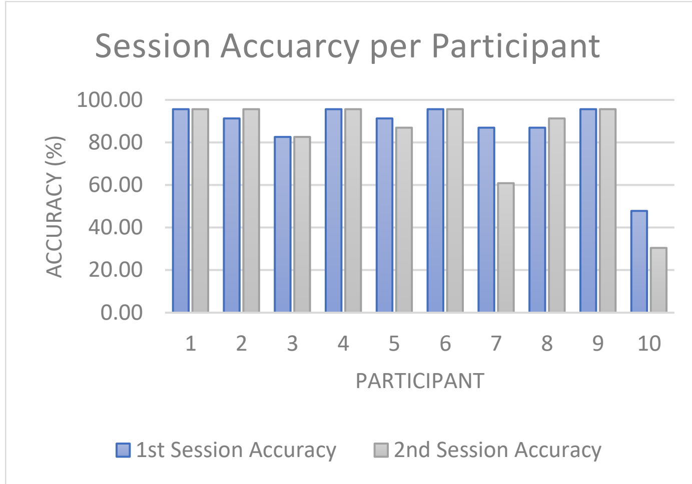


Figure 1: Session Accuracy per Participant

Age did not appear to have a strong association with change in accuracy from the first to second session. (See Figure 2). Accuracy values for individuals under 30 years were between 96 percent and 61 percent. The average accuracy was 87 percent, median 96 percent, and mode of 96 percent. Values of accuracy for participants above 30 years ranged from 30 percent to 96 percent. The average accuracy was 80, median 91, and mode 96 percent respectively. It should be noted that the oldest participant (65) also received the highest observed accuracy, 96 percent.

### B. *ISI Values*

The possible ISI values were 120ms, 160ms, and 200ms with 120ms being the default of the first session. Of the ten individuals participating in the study, five produced ISI values of 120ms and five were 160ms. None of the participants received a value of 200ms. Due to the study

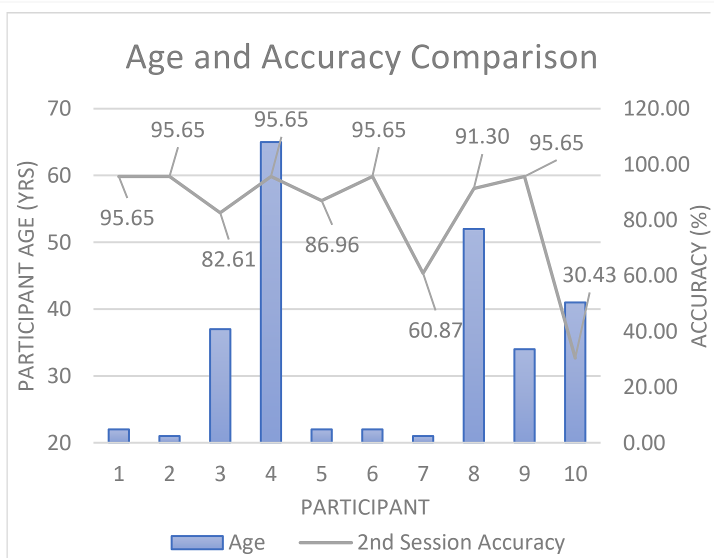


Figure 2: Age and Accuracy Comparison

design, it was not possible for an individual to receive a smaller ISI value than 120ms. The technical limitation was that the original minimum ISI value was set to 120ms which correlates with the highest observed accuracy of 95.65 percent.

There were five participants younger and five older than 30 years. When observing optimal ISI behaviors, it is expected for age and cerebral function to show a significant association between optimal ISI values. Individuals younger in age tend to have a lower optimal ISI. The opposite is true for persons in an older age demographic [8]. In reference to collected data, individuals younger than 30 years of age scored an optimal ISI value of 120ms 60 percent of the time. Participants older than 30 years scored a value of 160ms three out of five times. (See Figure 3).

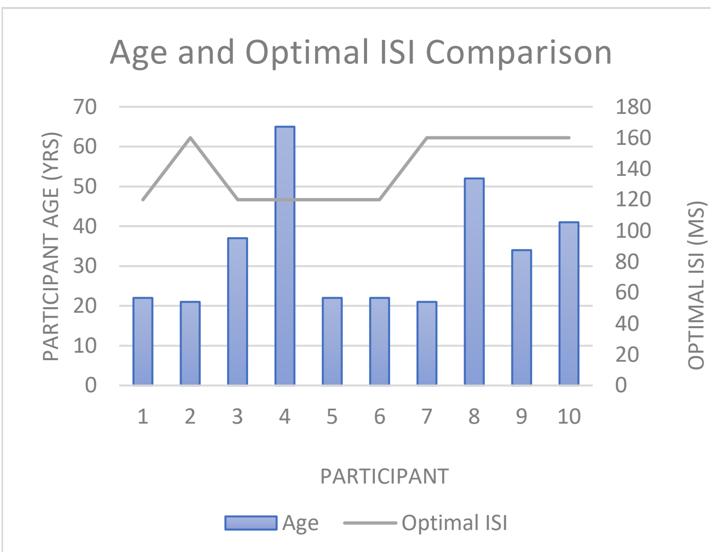


Figure 3: Age and Optimal ISI

## IV. Discussion

We were not able to improve the accuracy of these individuals using this method. However, these data suggest previously unforeseen issues with the experimental design. The below criteria should be addressed in future work:

- A smaller BCI2000 block to allow for a larger variety of optimal ISI values.
- The default ISI value should not also be the minimum ISI value a participant can obtain.
- Future participants should obtain at least 75% accuracy on the activity word 'JUMPS' before continuing with the study.
- Session 1 and 2 should not be held consecutively on the same date.

Given the study only allowed for three possible optimal ISI values, the optimal ISI of some individuals may fall outside of the allotted three values. A smaller BCI2000 block would allow a larger range for the optimal ISI values, in turn resulting in more unique ISIs and higher accuracy during the second session. Additionally, a default ISI value should be the median of the possible optimal ISI values. A suggestion is new ISI values in increments of 20ms in contrast to 40ms. For example: 120ms, 140ms, 160ms, 180ms, and 200ms, with 160ms as the default.

Regarding the test word exposed to participants prior to completion of the two sessions, there should be a minimum accuracy requirement upon spelling the word 'JUMPS.' This would minimize subject error due to unfamiliarity with the program. Subject error is also likely to come from fatigue, lack of focus, or boredom. Conducting session one and two consecutively within the same day may have contributed to the participants lacking engagement.

## V. Conclusion

CBLE methodology can be used to further investigate the relationship between an individual's optimal ISI value and BCI performance. However, it is imperative that participants are actively engaged during the utilization of the technology to negate unreliable results. To achieve this, experimental design adjustments must be made during future work.

## VI. Acknowledgements


This work was supported in part by the Women in Engineering program at Kansas State University and the National Science Foundation under Grant No. 1910526. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the Women in Engineering program nor National Science Foundation.


## References


[1] D. E. Thompson, S. Warschausky, and J. E. Huggins, "Classifier-based latency estimation: a novel way to estimate and predict BCI accuracy," J. Neural Eng., vol. 10, no. 1, p. 016006, Dec. 2012, doi: 10.1088/1741-2560/10/1/016006.

[2] J. J. Shih, D. J. Krusienski, and J. R. Wolpaw, "Brain-Computer Interfaces in Medicine," Mayo Clin Proc, vol. 87, no. 3, pp. 268–279, Mar. 2012, doi: 10.1016/j.mayocp.2011.12.008.

[3] L. A. Farwell and E. Donchin, "Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials," Electroencephalography and Clinical Neurophysiology, vol. 70, no. 6, pp. 510–523, Dec. 1988, doi: 10.1016/0013-4694(88)90149-6.

[4] R. Zhong, M. Li, Q. Chen, J. Li, G. Li, and W. Lin, "The P300 Event-Related Potential Component and Cognitive Impairment in Epilepsy: A Systematic Review and Meta-analysis," Frontiers in Neurology, vol. 10, 2019, Accessed: Jan. 23, 2022. [Online]. Available: https://www.frontiersin.org/article/10.3389/fneur.2019.00943

[5] T. Picton, "The P300 Wave of the Human Event-Related Potential," *Journal of clinical neurophysiology : official publication of the American Electroencephalographic Society*, vol. 9, pp. 456–79, Nov. 1992, doi: 10.1097/00004691-199210000-00002.

[6] J. Polich, "Updating P300: An integrative theory of P3a and P3b," *Clinical Neurophysiology*, vol. 118, no. 10, pp. 2128–2148, Oct. 2007, doi: 10.1016/j.clinph.2007.04.019.

[7] M. W. Geisler and J. Polich, "P300 and individual differences: morning/evening activity preference, food, and time-of-day," *Psychophysiology*, vol. 29, no. 1, pp. 86–94, Jan. 1992, doi: 10.1111/j.1469-8986.1992.tb02019.x.

[8] C. D. Woody and M. J. Nahvi, "Application of optimum linear filter theory to the detection of cortical signals preceding facial movement in cat," Exp Brain Res, vol. 16, no. 5, pp. 455–465, Mar. 1973, doi: 10.1007/BF00234472.

[9] L. G. De la Casa, L. Cárcel, M. Marias, and J. C. Ruiz-Salas, "Haloperidol-based conditioned increase in locomotor activity is disrupted by latent inhibition and extended interstimulus interval," Pharmacology Biochemistry and Behavior, vol. 198, p. 173036, Nov. 2020, doi: 10.1016/j.pbb.2020.173036.