Tapping into conflict monitoring and event-related negativity. An EEG study of response inhibition task.

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Introduction

Fallibility is an innate feature of the human cognition which can be observed on both conscious and unconscious level. Even though being wrong appears to be a natural phenomenon in our everyday life, on certain occasions mistakes can be costly or even deadly. Being caught often in conflicting circumstances with potentially high cost possibly led to the evolution of a mechanism which can quickly detect conflicts and provide means for further compensatory actions. Evidence strongly suggests that such conflict monitoring system indeed exists and its neural correlates may be found among the functions of the anterior cingulate cortex (ACC) (Botvinick et al., 2001).

Empirical evidence for the existence of a monitoring functionality comes from descriptions of an event-related process with an onset at the time of the commission of an erroneous response. The error-related negativity (ERN) is an EEG component which can be observed during erroneous trials in choice reaction time experiments. It is essentially a sharp, negative deflection with about 10mV amplitude. The onset of the component is simultaneous with the erroneous action and peaks at about 60ms-100ms after the onset (Gehring et al., 1993). The signal can be recorded from the frontal to the middle part of the scalp with epicenter approximately Cz.

With this report, we provide further evidence that the ERN is a direct manifestation of a conflict monitoring mechanism which can be observed when an erroneous action is taken. We assume that such a system will exhibit more pronounced activity when the accuracy is a condition of importance to the subject. Furthermore, we hypothesize that the amplitude of the ERN will vary according to the level of conflict present in the trial. Additionally, we measured the reaction time (RT) of the subjects and further speculated that lower RT is associated with lower presence of conflict and generally lower mental effort.

Methods

Participants

In total 15 participants between the age of 22 and 34 took part in the study (N=15). The data collected from one of the participants were excluded due to technical difficulties. All of the participants had normal or corrected-to-normal vision, were right-handed and reported no history of neurological disorders. The summarized demographic information about the participants is presented in Table 1. Prior to the experiment, all the participants gave written informed consent in accordance with the Declaration of Helsinki.

Task

All of the participants were asked to perform the Flanker task (Eriksen & Eriksen, 1974). The task consisted of two conditions for which the participants needed to indicate the direction of the target arrow(the middle arrow) by respectively pressing the left or the right arrow of the keyboard in front of them. In the congruent condition($> > > > >$, $< < < < <$), the target arrow is flanked by additional, non-target arrows, pointing to the same direction. In the incongruent trials($< < > < <$, $> > < > >$), the non-target arrows, flanking the target were pointing to the opposite direction.

Procedure

The experiment took place in an electrically-shielded EEG laboratory at the Ruhr University.

Participants sat in front of a computer monitor, at a viewing distance 100cm and were asked to place their index fingers respectively on the right and left arrows of the keyboard and press the button corresponding to the direction of the presented target arrow. The software used for the experiment was Presentation 18.3, running on a Windows 10 system. Each stimulus consisted of 5 arrows, from which the middle arrow was the target and the rest were distractors. Each stimulus was presented for 200ms with jittered inter-stimulus intervals from 1192ms to 1392ms. The total number of trials was 400, divided into 10 blocks, 40 trials each. There were no time-fixed breaks between the blocks instead they were self-paced with the participant indicating when they would like to start the next block. Trials were presented in a randomized and counter-balanced manner in order to avoid unwanted interference with the results.

Participants were instructed both verbally by experimenters and on screen prior to the experiment. Additionally, each participant was presented with 10 practice trials before the start of the experiment.

Data Recording

EEG was recorded by 32 passive ring electrodes(electrode impedance less than 10k) in accordance with international 10-20 system(ActiCap; Brain Products, Gilching, Germany) and a BrainAmp 500Hz Amplifier (sampling rate 500Hz). Two reference electrodes were placed on the mastoids and one ground electrode was placed at AFz.

Data Processing

The software used for the preprocessing of the data was EEGLAB toolbox (Delorme & Makeig, 2004) available within the MATLAB environment. As a very first stage of the preprocessing the practice trials were excluded from further analysis in order to prevent corruption of the results. The remaining data were filtered using a Hamming windowed sinc FIR band-pass filter with a lower cut-off of 0.5 Hz (0.25 Hz cut-off frequency, 0.5 Hz transition band width, filter order: 6600) and a higher cut-off of 30 Hz (30.25 Hz cut-off frequency, 0.5 Hz transition band width, filter order 440), ensuring that unnecessary frequency will not be considered during the analysis. Noisy channels were removed with the provided by EEGLAB channel rejection procedure using its default settings (measure: kurtosis, Z-score threshold: 5). Upon completion, data were re-referenced to the average of the remaining channels.

As a further step, epochs in the range from -1000 to 2000ms relative to the onset of the stimulus were generated. A 200ms window prior to the stimulus-onset was used as a baseline. Once the epochs were generated, an automatic trial rejection procedure (threshold limit: 1000V, maximum % of trials rejected per iteration: 5%) was applied in order to detect and remove trials with large signal fluctuations.

The remaining data were processed by applying an independent component analysis (ICA) algorithm. The number of the decomposed components was manually limited (limited to channels-1) in order to handle the created by the average referencing rank-deficiency. Following that, the EEGLAB plugin ADJUST (Mognon, Jovichic, Bruzzone, & Buiatti, 2011) was applied in order to detect and remove independent components which reflect eye blinks, eye movements and generic discontinuities. Between 1 and 14 components were removed from the data of each participant (on average 7). Additionally a second component rejection procedure, based on dipole estimation, was applied. The Dipfit plugin for EEGLAB (originally included in EEGLAB) was used for this purpose. Dipole estimation was based on the 'Sperical Head Model'. As a result, rejected were all components with a dipole solution exceeding a threshold of 40% residual variance. In other words, rejected were such components that were unlikely to represent cognitive processes. Spherical interpolation algorithm was used to replace the data from the originally rejected channels.

As a final step, all remaining trials were re-epoched in such a way that the response served as a time-locking event. Such procedure is required since the error-related negativity (ERN) is usually observed in response-locked data.

Data Analysis

The statistical analysis was conducted with MATLAB and Statistics Toolbox Release 2019a, The MathWorks, Inc., Natick, Massachusetts, United States. A repeated measure analysis of variance (rANOVA) was applied in order to show any significant differences among changes between accuracy (correct or incorrect) and congruency (congruent or incongruent) conditions within trials. One-tailed t-tests were used when the rANOVA revealed significant differences between measurement. Since all the variables used as independent had only 2 levels, t-tests were used for further investigation rather than post-hoc analysis. In all cases, for a statistically significant difference was considered p-value less than .05.

Results

EEG Data

A significant main effect of accuracy was found, indicating a major difference in the means of the groups of correct and incorrect trials $F(1,9) = 24.22$, $p = .0008$, $\nu p^2 = .72$. A one-tailed, paired sample t-test showed that the mean of the recorded potentials during the incorrect trials (M = -8.70, SD = 6.59) was lower than the mean of the potentials recorded during the correct trials (M = 3.17, SD = 7.28); $t(9) = 4.92$, $p = 4.1144\text{e-}04$. The differences in the amplitude of the signal between the two groups at response time can be seen on Figure 2. The figure not only shows that the values in the incorrect trials are lower it reveals that no ERN was present in the correct trials since no negative deflections were observed.

Additionally, no significant effect of congruency was found $F(1,9) = 1.86$, $p = .20$. Even though no significant interaction between accuracy and congruency seemed to be present $F(1,9) = 14.24$, $p = .053$, Figure 3 clearly reveals strong presence of ERN in the incongruent incorrect trials and weaker ERN in the congruent incorrect trials while no ERN seems to be present in the correct trials (both congruent and incongruent). Identical pattern of negativity presence can be observed in Figure 4.

Behavioral Data

The analysis of the behavioral data found a significant main effect of both accuracy $F(1,9) = 18.20$, $p < .003$, $\nu p^2 = .66$ and congruency $F(1,9) = 6.69$, $p = .02$, $\nu p^2 = .42$ over the reaction time. Also, a significant interaction between accuracy and congruency was revealed $p < .004$, $\nu p^2 = .77$.

Reaction time was overall higher when correct responses were given (M = 876.23, SD = 75.68) and lower when incorrect responses were obtained (M = 761.62, SD = 84.50); $t(9) = 4.26$, $p < .002$ (see Figure 5). Lower reaction time was also observed in the congruent trials (M = 802.79, SD = 80.16) compared to the incongruent (M = 838.01, SD = 61.92); $t(9) = 2.58$, $p < .02$ (see Figure 6).

The highest RT was found to be associated with the incongruent, correct trials while the lowest RT was observed in the case of incongruent, incorrect trials (see Figure 7).

Discussion

The aim of the present study was to explore the interaction of accuracy and congruency in a response inhibition task, using EEG and ERP measures.

The EEG results showed a significant main effect of accuracy however, no significant effect of congruency on ERN manifestation was found. This could be attributed to the complementing nature (correct trials show no ERN, while in both incorrect congruent and incongruent the ERN is strongly present) of the results when grouped by congruency, leading to a small difference in the means of the groups. Despite the lack of main effect of congruency, it is the case that the ERN seems to be most pronounced in the incorrect incongruent trials as expected (Figure 3, Figure 4).

The study included a second analysis based on behavioral data. As expected, both accuracy and congruency were found to have main effect over RT as well as a significant interaction. RT was highest in the incongruent correct trials and lowest in incongruent incorrect. Overall, correct responding was accompanied by higher RT (Figure 5, Figure 6, Figure 7). While higher RTs in the congruency condition are likely to be due to the introduction of additional confusion in the incongruent case, the higher RT in the cases of correct responses might be attributed to higher mental effort.

The findings in our study support the claim that ERN is a manifestation of a conflict monitoring system which is activated when an erroneous action is taken. However, it appears that the introduction of confusion (incongruency) has a little impact on the amplitude of the ERN, suggesting that the presence of an error is registered in an identical manner regardless of the conditions of the surroundings in which the error was made.

Note that four of the participants did not have records of incorrect congruent trials which prevented us from using the rest of the data of these four participants in the analysis. Due to this some of the analyses were conducted over 10 instead of 14 participants (9 degrees of freedom). Further research in this direction might benefit from using a bigger sample with such size that can compensate for missing values.

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Demographic Characteristics	Participants considered in the analysis (N=14)
Age (mean[S.D]) yrs.	25.28 (3.17)
Gender	
- Female(n[%])	11 (78.57%)
- Male (n[%])	3 (21.42%)
Vision	
- Normal (n[%])	5 (35.71%)
- Corrected (n[%])	9 (64.28%)

Table 1

Demographic data summary of the subjects included in the study.

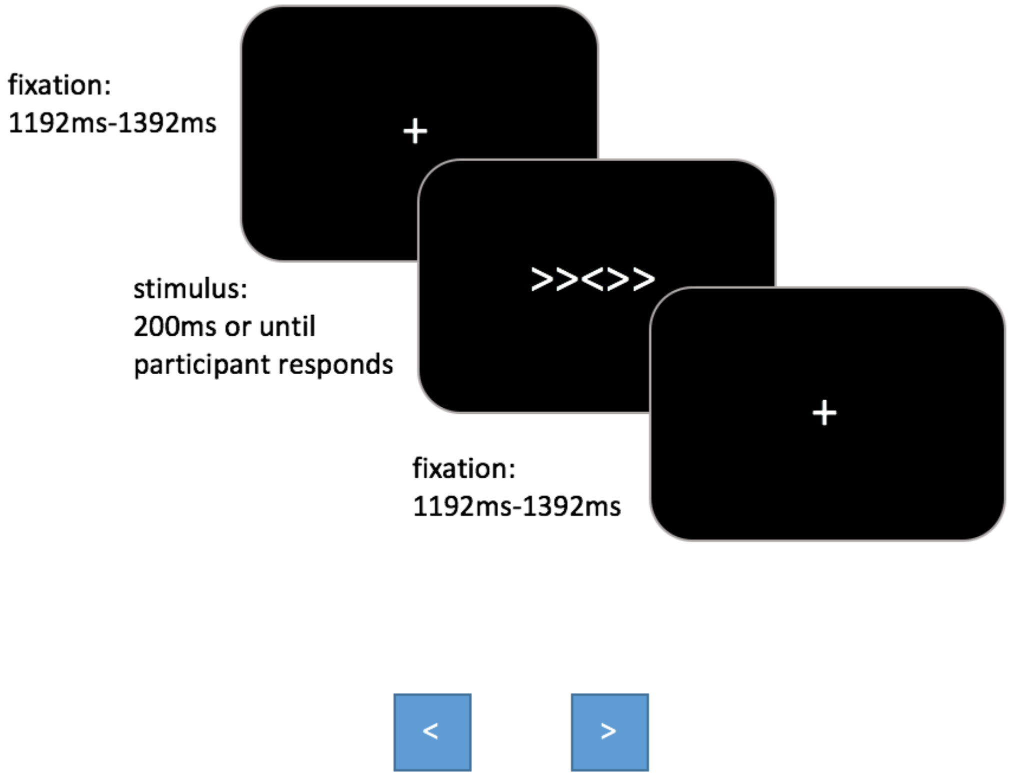

Figure 1. Graphical representation of the experimental setting. Each stimulus was presented for 200ms or until the participant responds Fixation screens were shown between the stimuli presentation. Participants were asked to respond by pressing the corresponding arrow of the keyboard to indicate the direction of the target arrowhead.

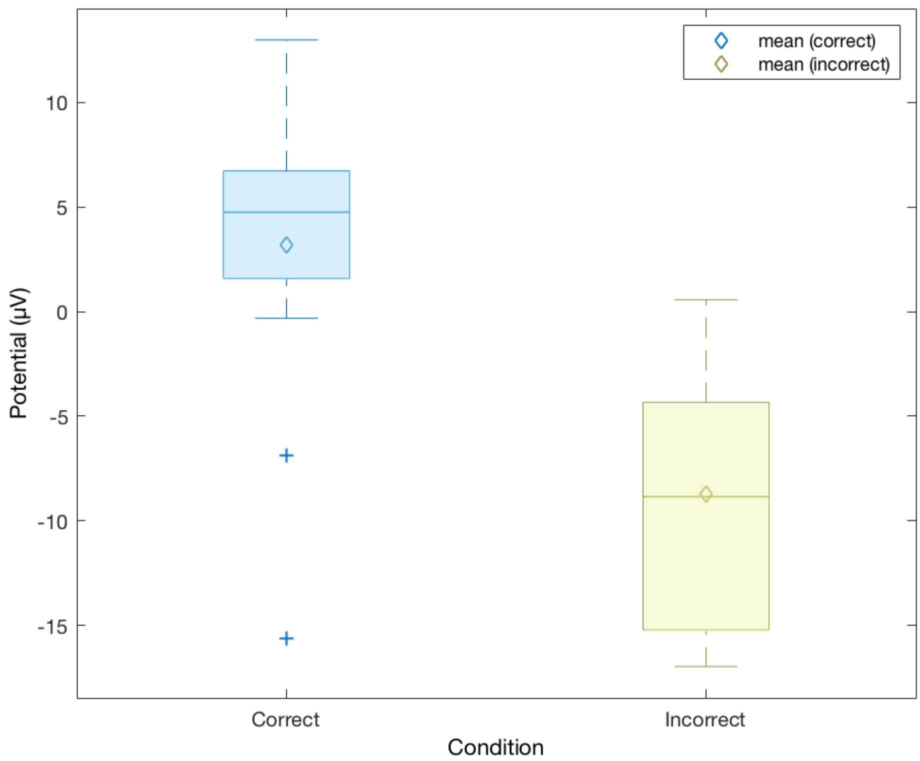

Figure 2. Distribution of the data segmented with regard to the correctness condition. The mean amplitude of the recorded potentials in the incorrect trials appears to be negative and lower compared to the mean amplitude of the correct trials. Note that apart from the two outliers, all data points in the correct condition represent positive deflections suggesting that no ERN was observed in this condition.

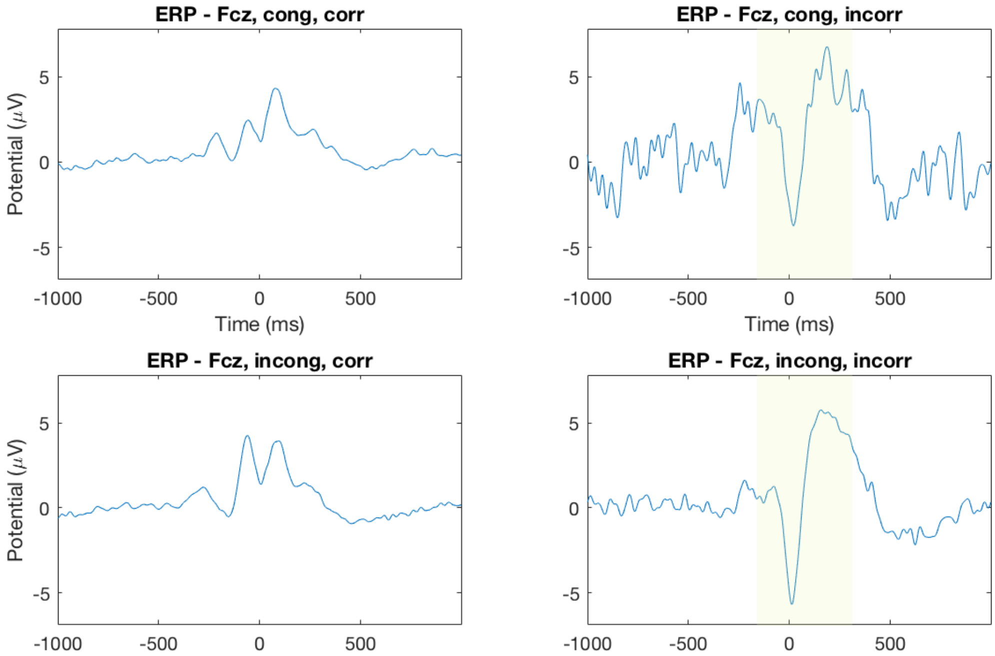

Figure 3. ERPs associated with the response action plotted in four conditions - congruent correct trials, congruent incorrect trials, incongruent correct trials and incongruent incorrect trials. Notice the negative deflection appearing simultaneously with the action in the both congruent and incongruent incorrect trials. Even though, the ERN is notable in both cases it seems to be more pronounced in the latter one. In the same time no ERN appears to be present in the correct condition both for congruent and incongruent trials.

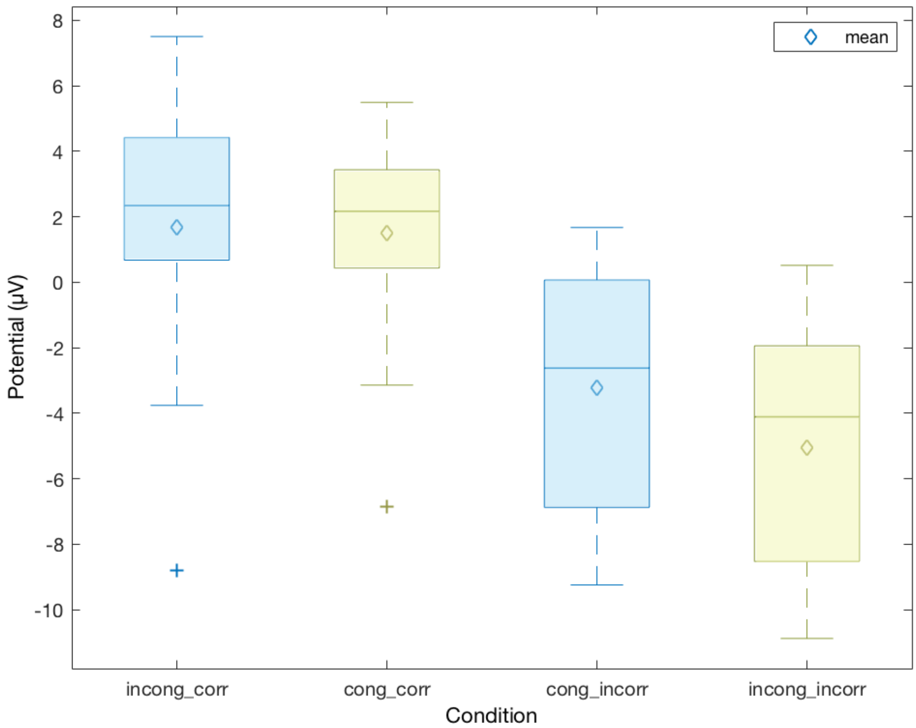

Figure 4. Distribution of the analyzed ERP data segmented into four groups of interest - congruent correct trials, congruent incorrect trials, incongruent correct trials and incongruent incorrect trials.

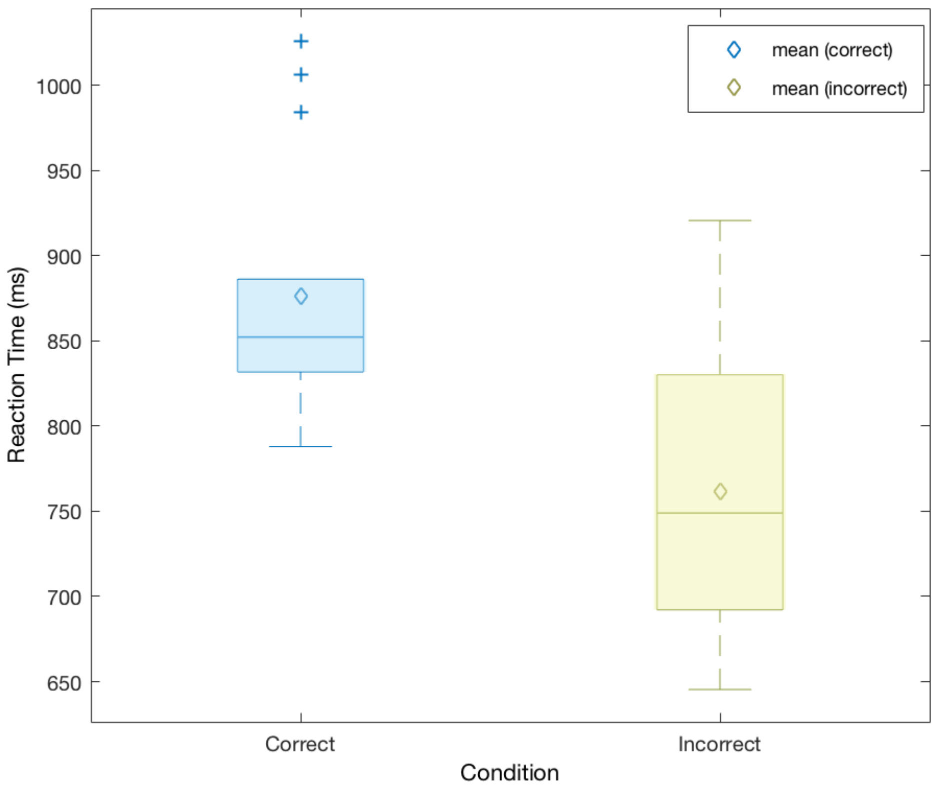

Figure 5. Reaction time data segmented by correctness condition. RT appears to be overall higher in the correct trials.

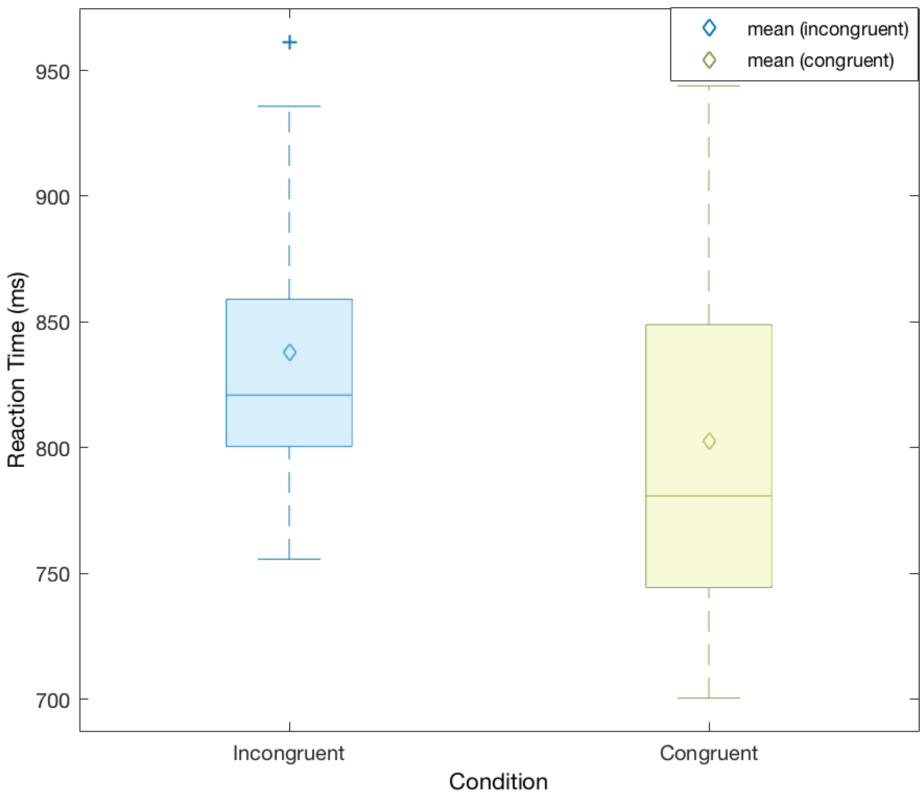

Figure 6. Reaction time data segmented by congruency condition. RT appears to be higher in the incongruent trials.

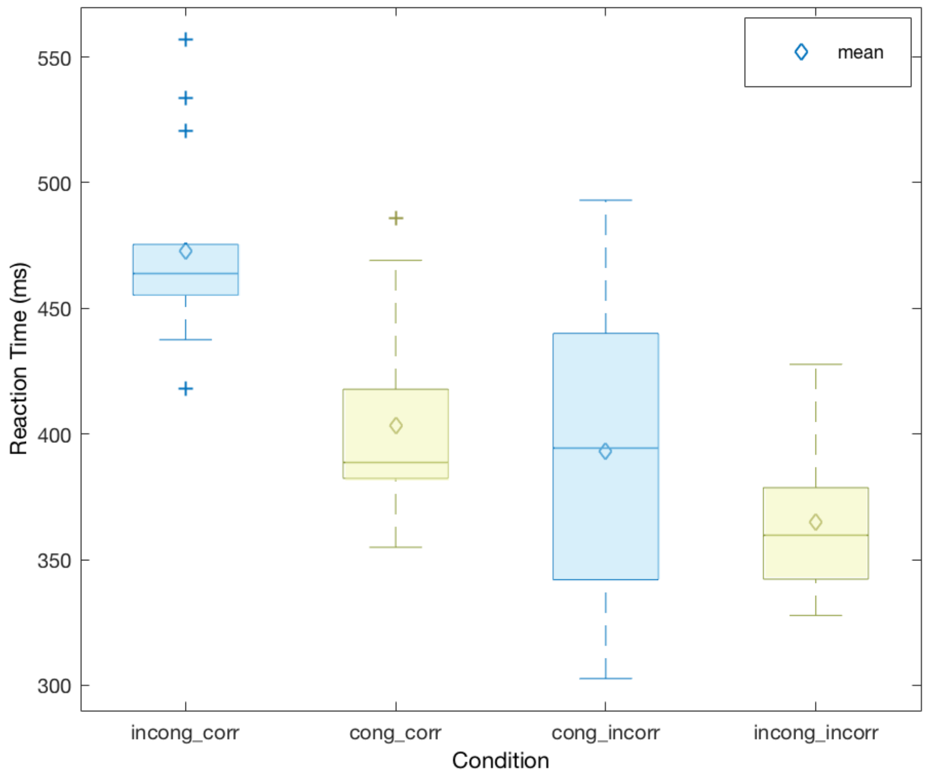

Figure 7. Reaction time data plotted in four conditions of interest - congruent correct trials, congruent incorrect trials, incongruent correct trials and incongruent incorrect trials. Highest RTs are observed in the incongruent correct condition and lowest in the incongruent incorrect condition.