Polygraph Project

Vedang Narain

2 November 2018

Background

The detection of deception is thwarted by the fact that there is no physiological response uniquely associated with lying [1, 2]. Hence, attempts to do so must aggregate and correlate multiple signals caused by physiological responses, and draw conclusions based on predefined metrics. The polygraph test, which measures biological parameters commonly associated with deception, is based on the notion that both guilty and innocent subjects want their responses to be seen as truthful [2]. This allows examiners to measure differential responses.

Physiological parameters commonly used in studies of deception responses include:

1. Heart Rate: Changes in heart rate are governed by involuntary physiological processes under the control of the autonomic nervous system. The standard heart-rate profile of verbal responses to questions consists of an acceleration followed by a deceleration, the latter of which is more diagnostic for inferring deception [3]. Heartbeat can be measured by electrocardiography and photoplethysmography, although the latter is susceptible to variations in skin and vessel anatomy [3].

2. Electrodermal Activity: Electrodermal responses have been consistently shown to be higher for deceptive responses as compared to truthful responses to the extent that they may be considered the most useful signal in the experimental data utilized in this report's analysis [2, 3, 4].

3. Respiration: The amplitude and cycle time of respiration data have been examined as possible indicators of deception [2]. Decreases in respiration amplitude and increases in respiration cycle times have been found to be valid signs of deception [4].

4. Blood Pressure: Blood pressure is a measurement of arterial tension caused by the pressure exerted against the sides of the blood vessels by moving blood, and has generally been recognized as inducible by voluntary muscular contraction [5]. The external pressure applied during the measurement process cannot be sustained for extended periods of time due to the possibility of detrimental physiological effects on the subject [2].

It is worth remembering that the physiological responses associated with deception are also characteristic of other stimuli for stress, such as anxiety [6]. Moreover, considering that subjects undergoing a polygraph test can readily identify relevant questions, the metrics detailed above cannot be seen as absolute.

Approach

To begin designing a system of evaluation for deception, we must first consider the psychology of the subject. In particular, it is necessary to make assumptions about his (the subjects in the exercise were all male) objectives since they can have a significant effect on the physiological response. There are two motivations for the subjects to attempt to hide deception, with the first being the offer of a reward to the subject whose 'crime' is least correctly identified. The second prospective reason that a subject may have to disguise signs of deception is the intrinsic reward associated with identifying the most crimes correctly. Since avoiding detection can increase the difficulty of identifying crimes for the other participants in the competition, we can assume that subjects attempted to do so. Moreover, it is important to keep in mind that there is no penalty (aside from the possible loss of the reward) for overtly modulating physiological activity (e.g., rapid manual breathing). This is fundamentally distinct from real attempts to deceive in which individuals under forensic scrutiny cannot make overt attempts to disrupt data collection.

Choosing Parameters of Interest

Considering the assumption that the subjects in the study made attempts to deceive, it seems prudent to give a significantly higher weight to parameters that are harder to modulate. Thus, electrodermal activity (EDA), pulse (PPG), and blood pressure (BP) have been chosen as the primary indicators of deception. The secondary parameters used are changes in respiration (RSP) and heart rate (BPM).

While it may have been desirable to use the respiration data as a primary parameter, the fact that respiratory volume is easy to modulate cannot be discounted. In the case of heart rate (beats per minute), the resolution of the data is poor, with effective changes in the signal value occurring at an approximate rate of one change per four seconds. While it may be useful as a visual guide when identifying regions of interest for further examination, it is desirable to find an alternative means of measuring cardiac activity. For this purpose, the inter-beat intervals (IBI) have been extracted from the raw pulse data.

Since the length of the inter-beat intervals can be directly correlated with the heart rate, the data provided in units of beats per minute will be referred to as 'BPM' to avoid confusion in this report, while inferences about the heart rate made from IBI calculations will be referred to as 'heart rate' or 'HR'.

A relatively higher weight has been given to EDA and IBI than to BP due to the lack of conclusiveness on its efficacy [10]. The mean arterial pressure data was excluded for the same reason, in addition to the redundancy of utilizing blood pressure measurements twice.

Preparing the Data for Analysis

The Python (3.5) programming language was utilized in the Spyder (3.1.4) IDE to design a system that allows us to examine and interact with the data. This system is dependant on two input files for each subject: the raw data file and the time-indexed list of events. The event lists have been edited to normalize units, and eliminate unnecessary data to streamline the import stage. In particular, the list of events for Subject A was modified to make adjustments to the segment on the skipped question (2C) in order to allow for a generalized system of evaluation. The time-stamp of 2C was assigned the same value as the following question, keeping in mind that the design of the program discounts the presence of 2C, as can be evidenced in the Figure 4 series by the lack of data for the skipped segment. Using the events file allows us to refer to the time segments following each question by the row number of the question.

Processing the Signals

Once the individual signals of interest were extracted, they were downsampled to 10 Hz from their initial sampling frequency of 1 kHz. Downsampling allows for a faster runtime, but more importantly, frequencies above 10 Hz can be significantly attenuated. Since the physiological processes associated with the parameters under analysis occur at a frequency far lower than 1 kHz, downsampling eliminates high-frequency noise. However, there may still exist noticeable noise corruptions in the signal of interest that can be caused by sensor movement or physiological sources of noise. Consider the effect of filtering in Figures 1(a) and 1(b).

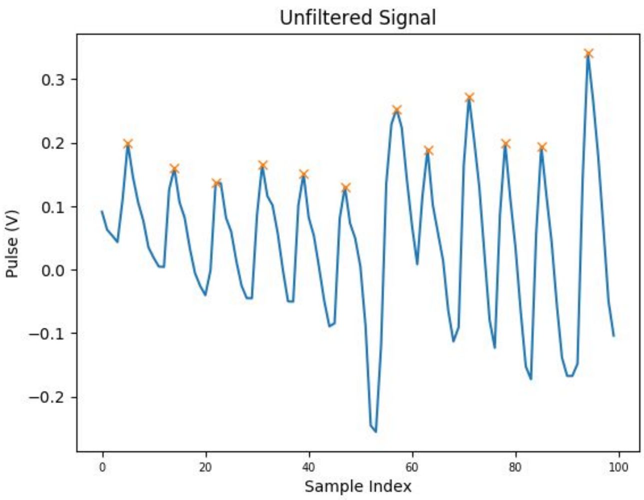


Figure 1(a). Unfiltered Pulse Signal

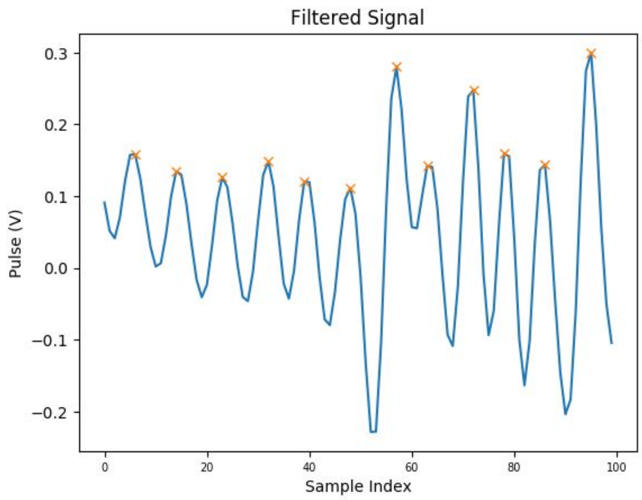


Figure 1(b). Filtered Pulse Signal

The figures show the effect of passing the PPG waveform through a Butterworth Low-pass Filter with a cut-off frequency of 2 Hz and an order of 5. While some reduction of noise is apparent, the reduction in signal amplitude is noticeable as well. In conjunction with the fact that the peaks of both waveforms (the most important feature required for the extraction of inter-beat intervals) can be detected without difficulty, there appears to be little benefit in applying a filter to the downsampled data.

Examining the Signal

In order to allow for convenient inspection of the signal, the program was designed to allow for the viewing of ‘snapshots’ of a chosen time frame. By entering the start and end points (in units of seconds), we can view all the parameters for a subject over any period. As can be seen in Figure 2, vertical red lines indicate demarcations between individual events, usually questions.

Generating Additional Metrics

The electrodermal activity of the skin can be evaluated in its existing form since it is not a regularly oscillating signal. However, the pulse and blood pressure waveforms require additional processing in the form of peak detection. This enables us to acquire inter-beat intervals and systolic values respectively. A function is defined within the program to calculate intervals between pulse peaks. This provides a measure of variability in the beat timings, and is inversely proportional to the heart rate.

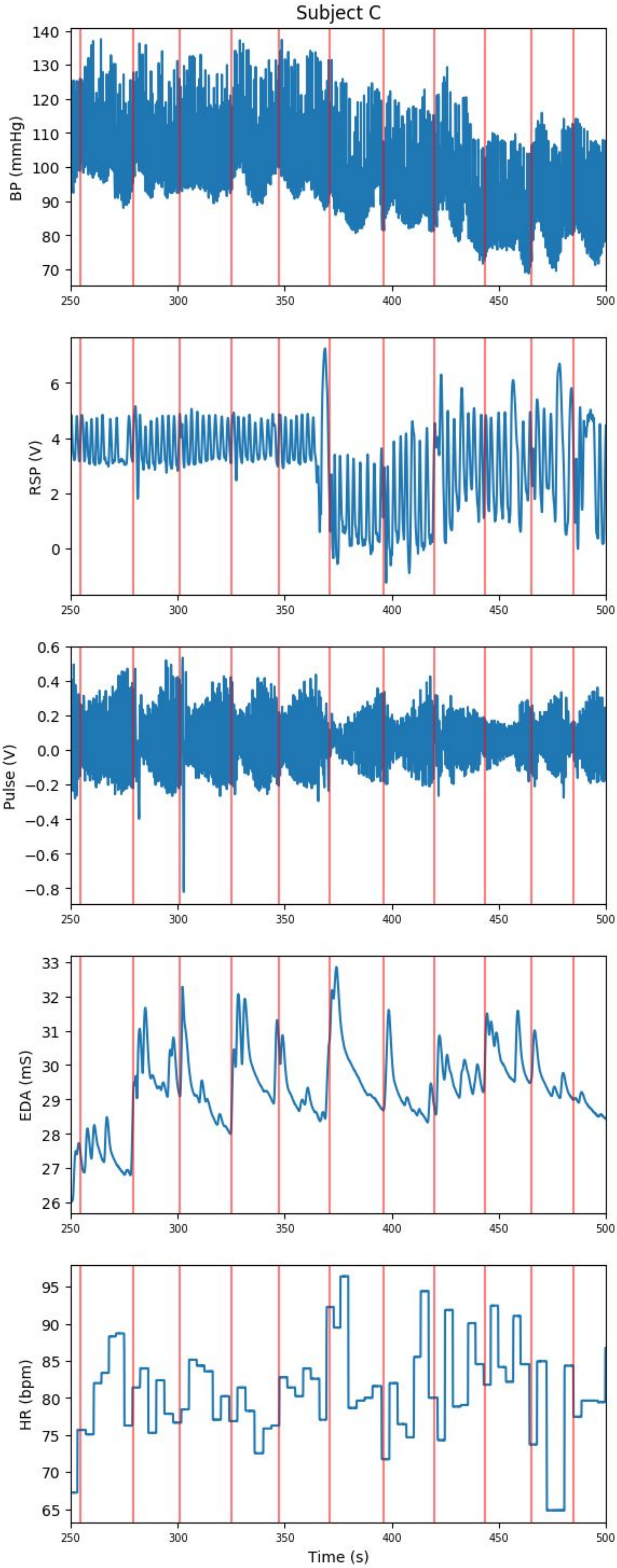


Figure 2. Snapshot of Subject C’s responses from 250 seconds to 500 seconds

Quantifying Responses

Several conventional statistical methods were considered for the purpose of quantifying results, including z-scores. However, these methods require a normal distribution in the dataset to provide accurate results, a feature not exhibited across all metrics in the study, as can be inferred from the histogram of EDA for Subject A shown in Figure 3.

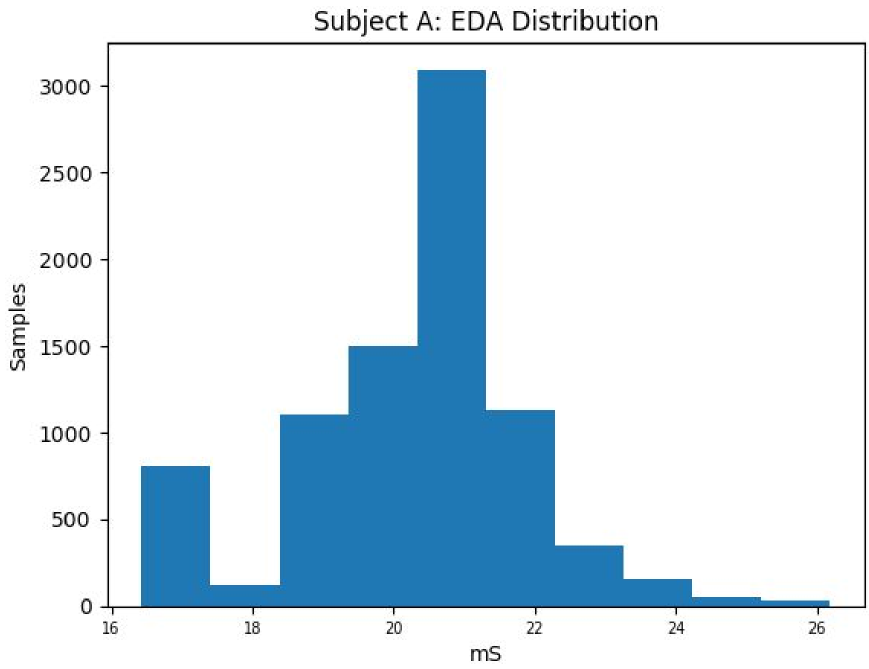


Figure 3. Histogram of Subject A's EDA activity

With the constraint of a non-normal distribution, an alternative method to calculate the response is proposed: the average percentage change (from a baseline) exhibited by the period following a question. This response period can be considered to begin at the moment of questioning and end at the moment the following question was asked. The metrics under consideration (systolic BP, IBI, and EDA) are averaged over this period to encapsulate any sustained change in the parameters. The difference between the baseline is normalized to compensate for inherent physiological variations in the magnitude of responses exhibited by subjects. A function that accepts a question index as an input and calculates the average of the following response period is integrated into the program. The formula can be expressed as shown below.

$$\text{Response} = \frac{\textit{Average of Response Period} - \textit{Average of Baseline Period}}{\textit{Average of Baseline Period}} \times 100$$

While sustained changes are captured in the above metric, more sudden changes can be inspected visually by examining the graph at the point of interest. An additional function that calculates the baseline of the five seconds preceding a question for the purpose of measuring immediate changes is also featured in the program but has not been utilized for this report.

Obtaining a Baseline

There are three viable candidates for the baseline period:

1. Designated Baseline Period: This is the initial time period prior to the commencement of questioning as marked out in the events list. The prospective advantage of using this period as the baseline is the possibility that the data obtained over this period is representative of the subject's physiological parameters at rest. However, it stands to reason that the novelty of the situation (such as the sensation of attachments, silence,

and presence of a stranger) would act as a psychological stressor and cause parameters to deviate from the true norm. Moreover, the baseline obtained will not be representative of the parameters we can expect to see when questioning begins in the form of a one-way dialogue that can induce stress. Therefore, this period is not an optimal baseline.

2. Recent Irrelevant Questions: This period can help provide us with data that encapsulates the psychological effect of questioning. In light of the fact that all candidates were instructed to answer ‘no’ to all questions, the data measured during the most recent irrelevant questions for which the honest answer is ‘yes’ reflects the subject’s physiological response when lying. Therefore, it can be assumed that significant deviations from this baseline are indicative of the subject’s recognition of a relevant question, and possibly even of guilty knowledge.

3. Immediately Preceding Period: By noting the baseline of the data obtained over the time period immediately preceding a question, the response to the moment of questioning itself can be measured. However, the change may reflect the orienting response resulting from the resumption of conversation after a period of silence; this change is not compensated for in the baseline data. Since the element of the orienting response is only present in the response period, it does not seem prudent to use the Immediately Preceding Period baseline.

Considering the advantages and disadvantages discussed above, the logical choice over which to average the data for a baseline is the Recent Irrelevant Questions (RIQ) option since it provides both reasonable proximity to the response under evaluation as well as the orienting response to a question being asked. With specific reference to this project, there are five questions to which the honest answer is ‘yes’ but must be answered with a ‘no’ due to the design of the measurement process: 1A, 2A, 7A, 8A, and 7D. Since question 7D is the concluding question, it offers little value for this baseline beyond visual reference because it does not precede any relevant questions. For the sake of simplicity, this question is excluded from the evaluation. Thus, the successive questions 1A and 2A provide a baseline period for the following four questions. The next two irrelevant questions, 7A and 8A, provide the most proximal baseline for the rest of the questions. To summarize, relevant questions preceding 7A are compared to the response to 1A and 2A, while relevant questions following 8A are compared to the response to 7A and 8A.

In addition to the irrelevant questions utilized to which the honest answer is ‘yes’, there exist several questions to which the honest answer is ‘no’, i.e., in response to which the subjects always provide a truthful answer. These questions are not considered for the baseline period. Rather, they are treated as relevant questions due to the fact that they do not offer insights into the subject’s deception response, and because the questions may feature words that induce a response in the subject. For example, a subject that has stolen $41 in cash may exhibit a response to a question which inquires if he has stolen a check worth $41 due to the relevance of the monetary amount. In order to make conservative inferences, signs of deception (e.g., increases in EDA) will be further examined while responses characteristic of the absence of deception (e.g., no change or lowered EDA) will be discounted.

Making Deductions

In general, increases in IBI (i.e., deceleration in heart rate), BP, and EDA have been treated as signs of deception. These signs are the basis of a three-step system of evaluation that has been considered when drawing conclusions about the crime committed by a subject.

1. Differential Response Examination: This preliminary analysis involves a visual assessment of significant changes in response to questions as reflected in the response calculations. Questions that induces a significant (a value chosen by examining individual graphs) response are then examined for keywords.

2. Keyword Analysis: In this step, consideration will be given to the words or phrases comprising a question (e.g., cash, $41, office) rather than question meanings as a whole. This method considers the fact that certain segments of questions may be applicable to subjects even when the meaning of the sentence is not. For

example, question 1C asks if the subject took 'a check saying $41'. In this case, the subject may have taken a check worth $470.16 or cash worth $41, neither of which is mentioned in 1C. However, the phrases 'did you take a check' or '$41' may be sufficient to induce a response in the subject due to its relevance to the crime committed. A list of keywords for each question that induces a significant response is then assembled, with the number of occurrences noted as well. Since the number of questions for each variation of the crime (mailroom or office, check or cash) is equal, this method should provide a useful standard of comparison. In addition, this method takes into account both the magnitude and the frequency of responses.

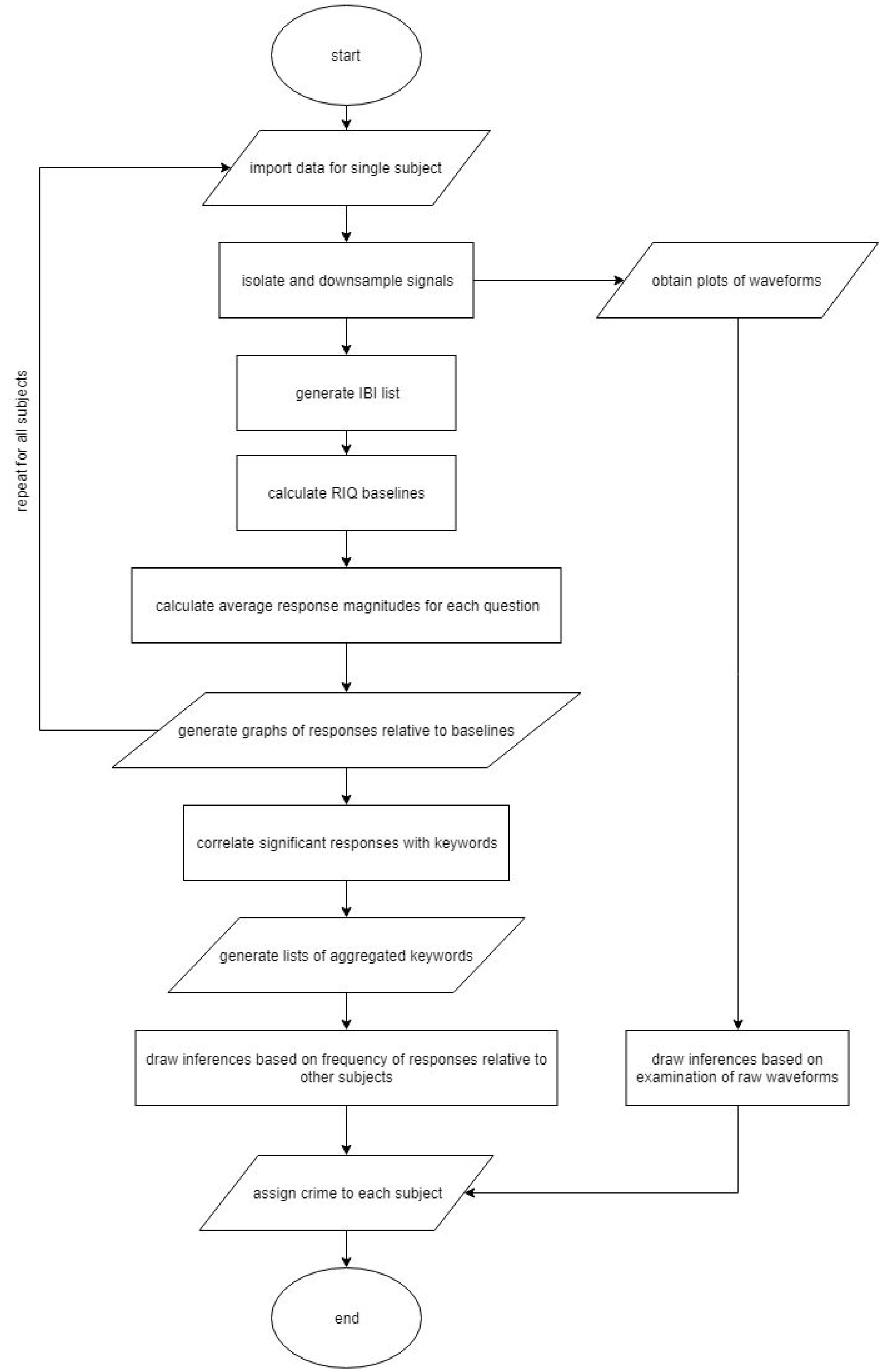
3. Visual Examination: In the event of inconclusive evidence drawn from the methods above, it is useful to evaluate the response to relevant questions to which the subject — if he does indeed conform to our initial hypothesis — must have answered with the intent of deception. For example, if we know that a subject visited the office but do not know what he stole, we can examine the raw waveform segment encapsulating the responses to questions relevant to the office and compare the responses to questions referencing cash and check amounts.

4. Logical Deductions: This final step is resorted to when no inference can be drawn from any of the previous steps. We do so by attempting to satisfy the constraints of Table 1. As a simple example, if we know that a subject stole cash but do not know where he stole it from, we could check whether the mailbox or the office row totals are already satisfied, and place the subject in the row that is not.

While making inferences, it is necessary to remember that large changes in parameters may also be indicative of errors in the measurement process, such as sensor movement. Moreover, certain subjects exhibit a general trend of decreasing BP. Since this overall trend can obscure changes in blood pressure as a response to questions, the blood pressure readings for these subjects may need to be discounted.

	Check	**Cash**	**Subjects**
Mailbox	Envelope 1	Envelope 2	**3**
Office	Envelope 3	Envelope 4	**4**
Subjects	**3**	**4**	**7**

Table 1. Relationship between subjects and crime locations, stolen item(s), and envelopes chosen



Flowchart 1. Overview of approach

Results

With the methods outlined above and the data generated by the preceding operations, we can now begin to evaluate one subject at a time.

Subject A

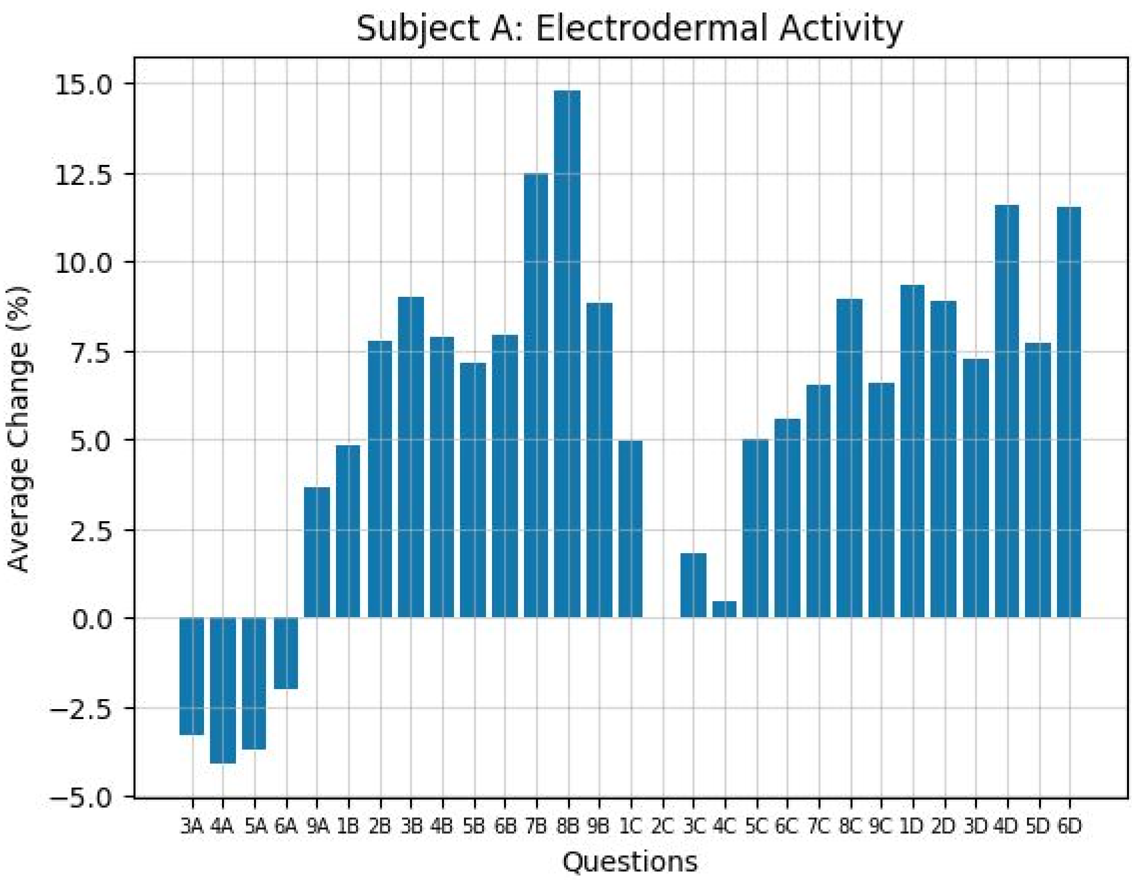


Figure 4(a). Change in EDA for Subject A

Based on Figure 4(a), we can examine the questions that induced significant (~2% and above) increases in EDA when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: cash [3], mailroom [2], envelope 2 [2], $470.16 [2], check [2], mailbox, office, bag, $41

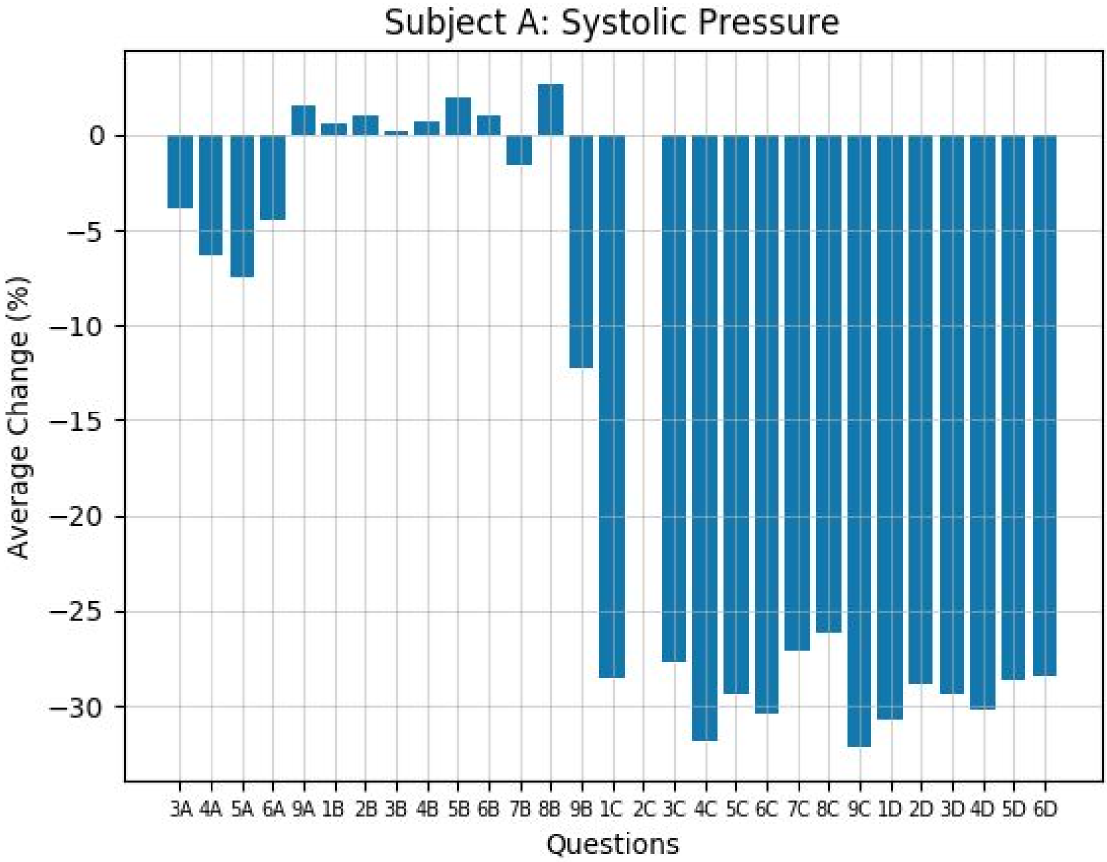


Figure 4(b). Change in systolic BP for Subject A

Figure 4(b) exhibits an overall decreasing trend that may lead to incorrect inferences. Moreover, there is no significant (~5% and above) increase in systolic BP. Therefore, the results are excluded.

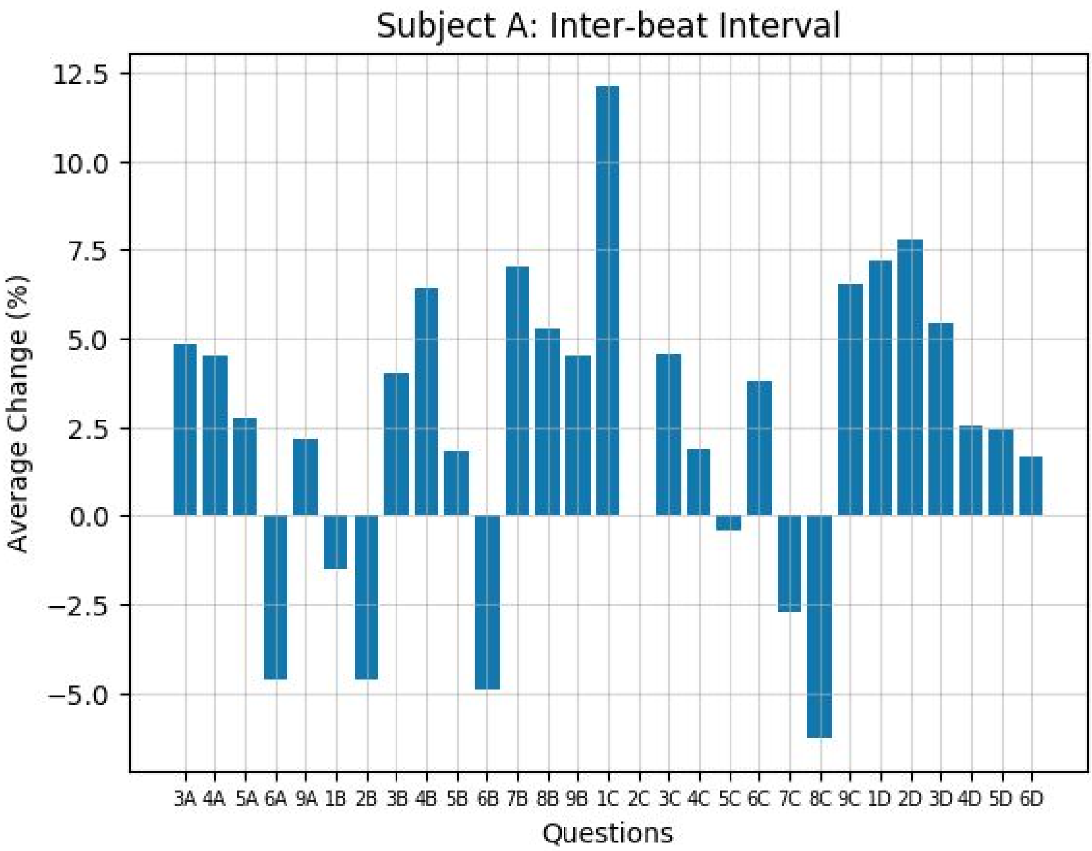


Figure 4(c). Change in IBI for Subject A

Based on Figure 4(c), we can examine the questions that induced significant (~2.5% and above) increases in IBI when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: mailbox [2], cash [2], envelope 1, mailroom, $470.16, check, $41, bag, cash

Total Keyword Count: cash [5], mailroom [3], $470.16 [3], check [3], mailbox [3], envelope 2 [2], office, bag [2], $41 [2], envelope 1

Subject B

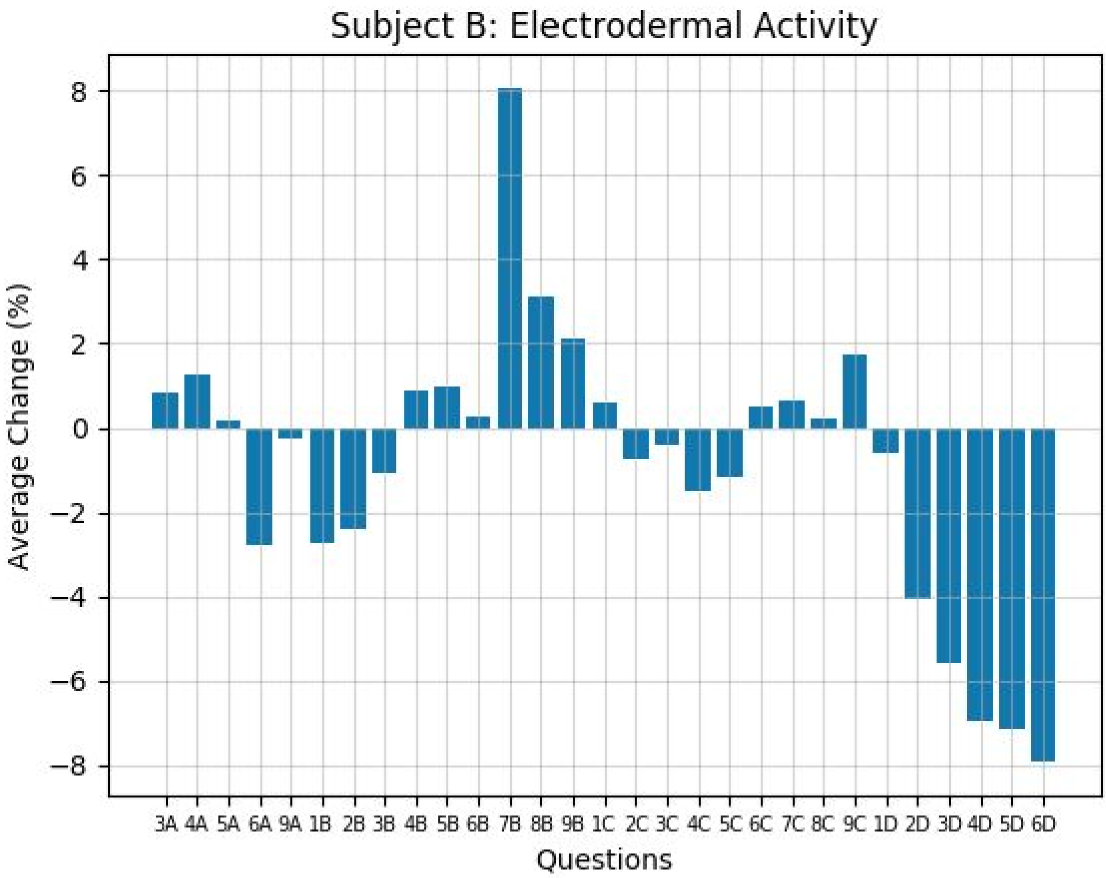


Figure 5(a). Change in EDA for Subject B

Based on Figure 5(a), we can examine the questions that induced significant (~2% and above) increases in EDA when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: cash [3], mailroom, mailbox, $470.16, bag

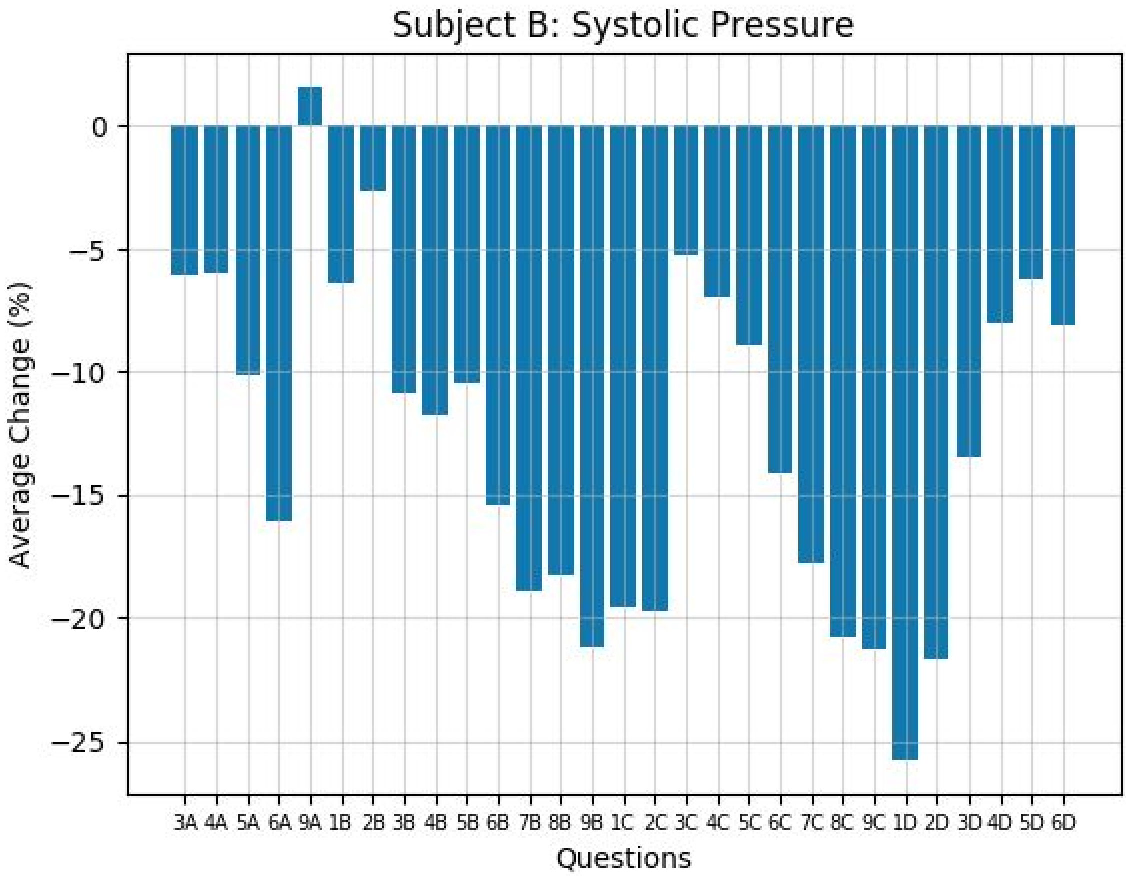


Figure 5(b). Change in systolic BP for Subject B

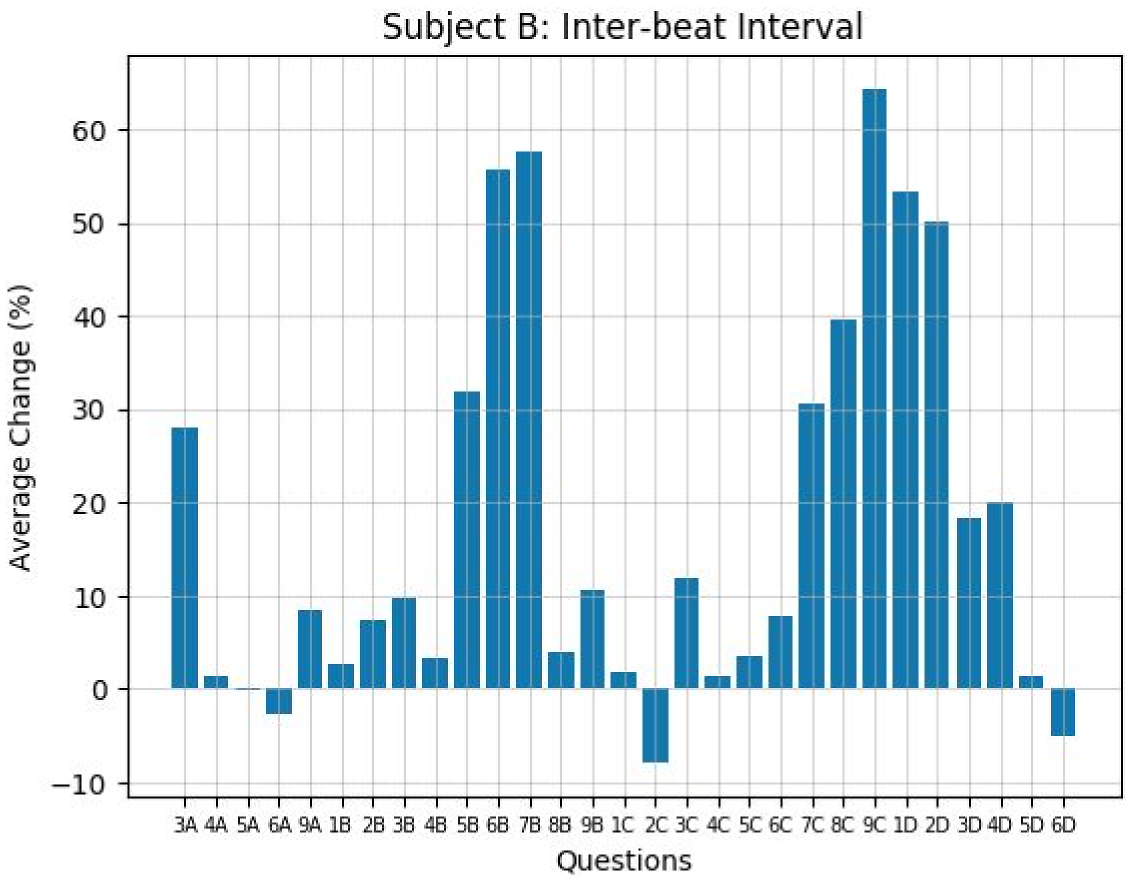


Figure 5(c). Change in IBI for Subject B

Figure 5(b) exhibits an overall decreasing trend. However, there appear to be significant (~5% and above) changes in systolic BP. Therefore, the results are considered.

Keyword Count: mailroom [2], check [2], cash, office, envelope 2, $470.16, bag

Based on Figure 5(c), we can examine the questions that induced significant (~10% and above) increases in IBI when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: envelope 1, mailroom [2], cash [4], $41, office, pockets, bag

Total Keyword Count: cash [8], mailroom [5], bag [3], check [2], $470.16 [2], office [2], envelope 1, envelope 2, mailbox, pockets, $41

<u>Subject C</u>

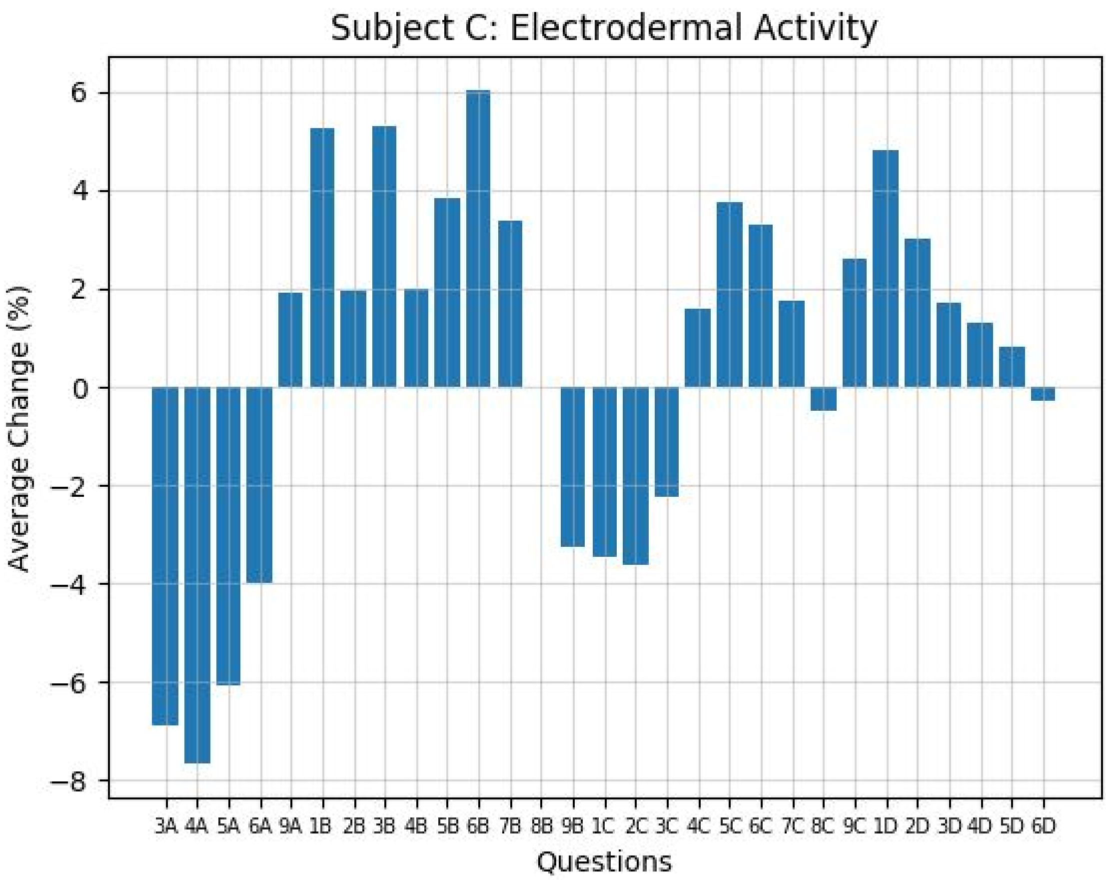


Figure 6(a). Change in EDA for Subject C

Based on Figure 6(a), we can examine the questions that induced significant (~2% and above) increases in EDA when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: cash [3], mailroom [2], envelope 1 [2], $41 [2], office [2], envelope 2, mailbox

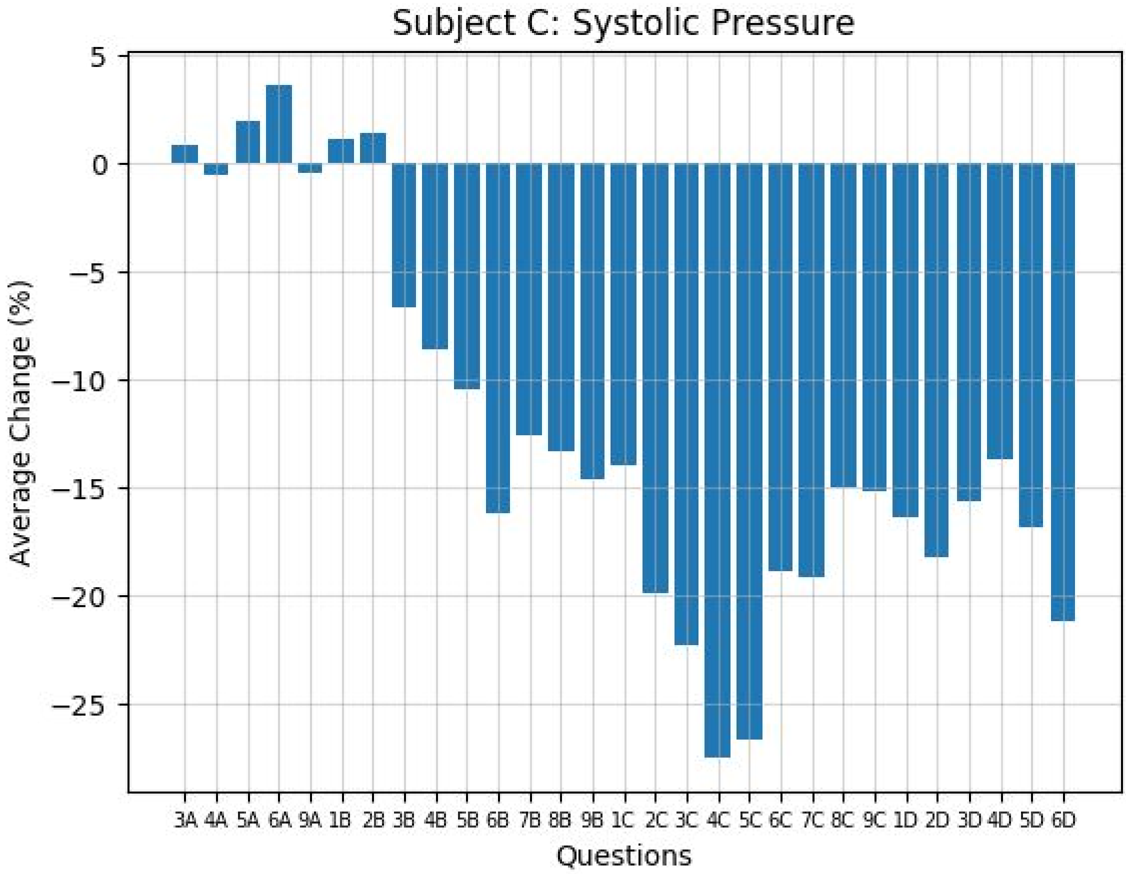


Figure 6(b). Change in systolic BP for Subject C

Figure 6(b) exhibits an overall decreasing trend. However, there appear to be significant (~5% and above) changes in systolic BP. Therefore, the results are considered.

Keyword Count: cash [2], bag [2], $470.16

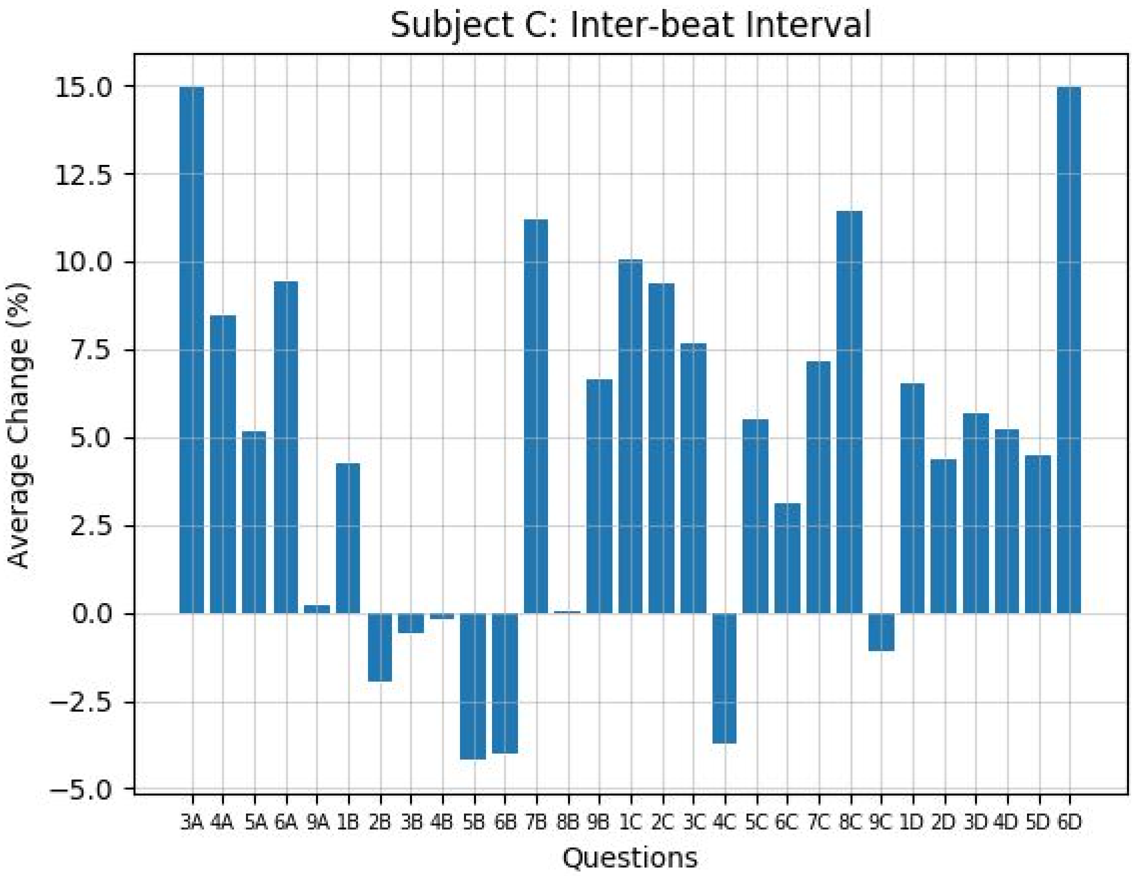


Figure 6(c). Change in IBI for Subject C

Based on Figure 6(c), we can examine the questions that induced significant (~10% and above) increases in IBI when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: cash [3], $470.16 [2], check [2], envelope 4, envelope 1, envelope 2, mailroom, office, $41, pockets, bag

Total Keyword Count: cash [8], mailroom [3], $41 [3], bag [3], envelope 1 [3], $470.16 [3], office [3], check [2], envelope 2 [2], mailbox, pockets, envelope 4

Subject D

Based on Figure 7(a), we can examine the questions that induced significant (~1% and above) increases in EDA when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: check [4], $41, $470.16 [2], cash [2], envelope 2, envelope 4, envelope 1, mailroom, mailbox, bag

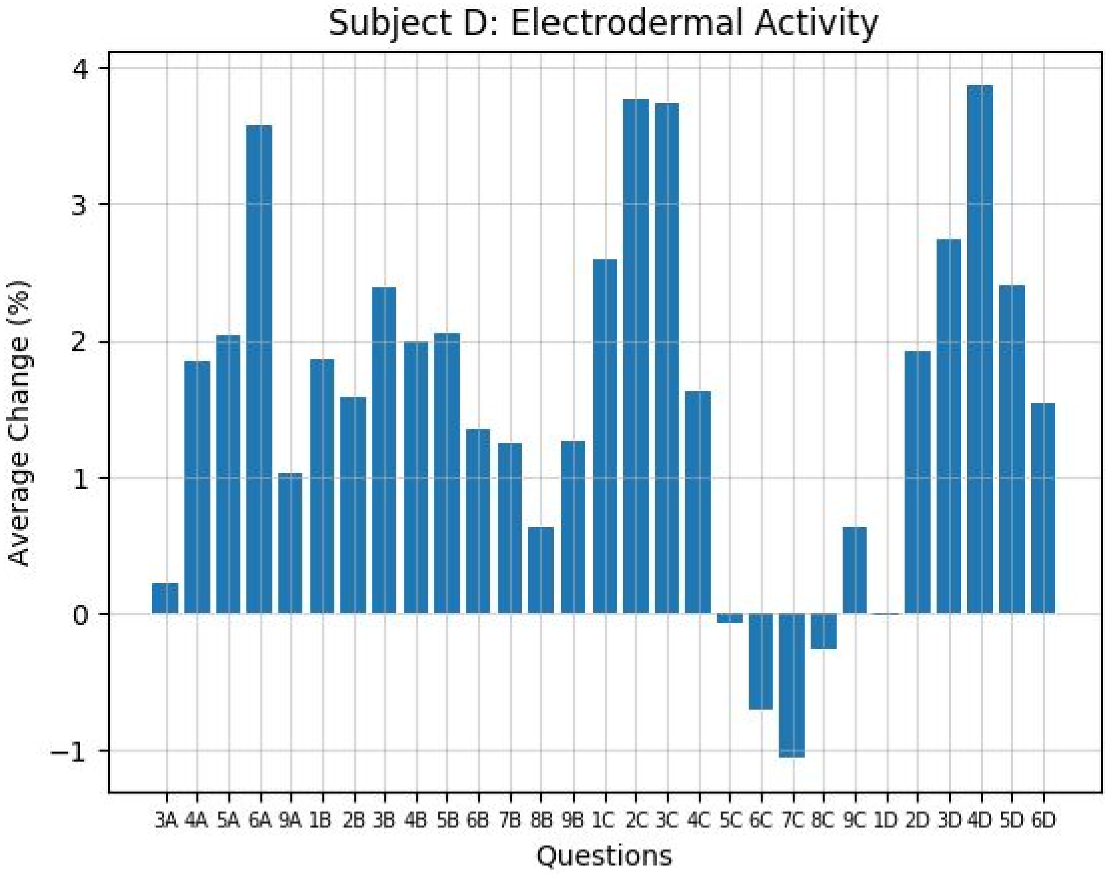


Figure 7(a). Change in EDA for Subject D

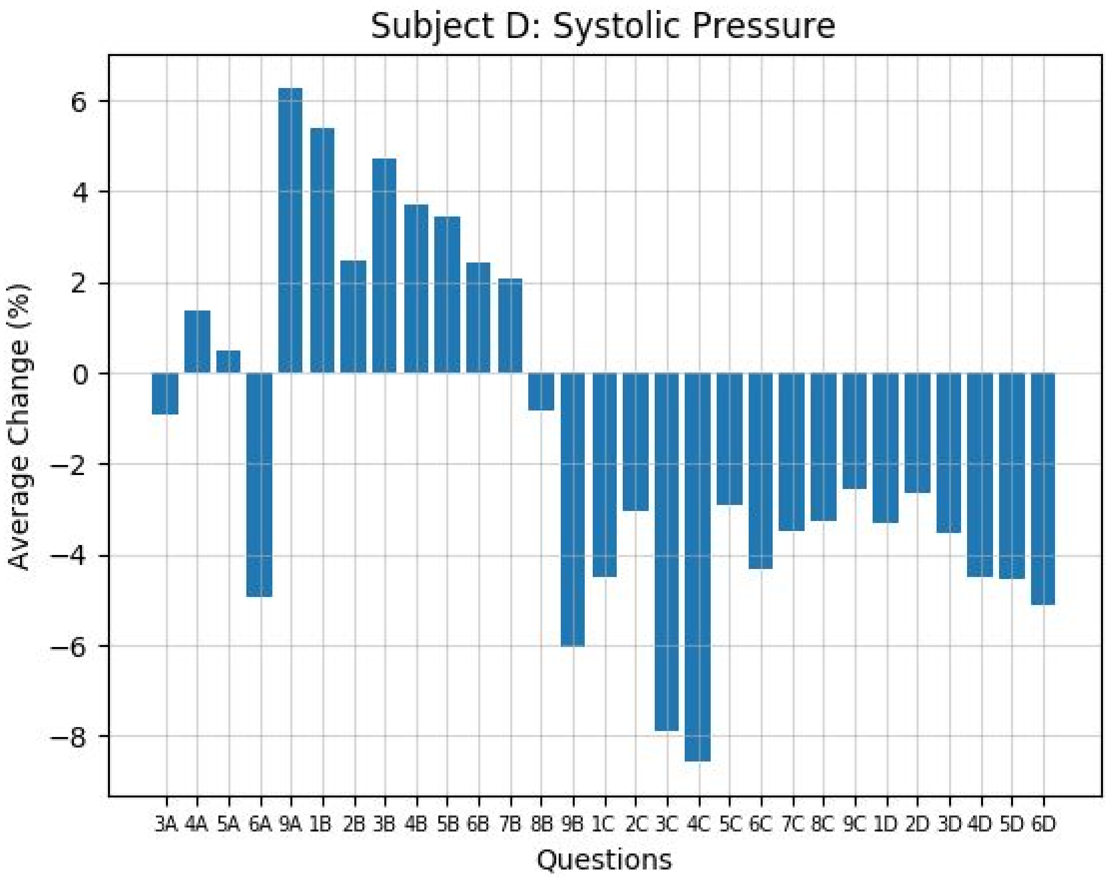


Figure 7(b). Change in systolic BP for Subject D

Based on Figure 7(b), we can examine the questions that induced significant (~2% and above) increases in systolic BP when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: check [2], $41, $470.16, office, envelope 2, mailroom, mailbox

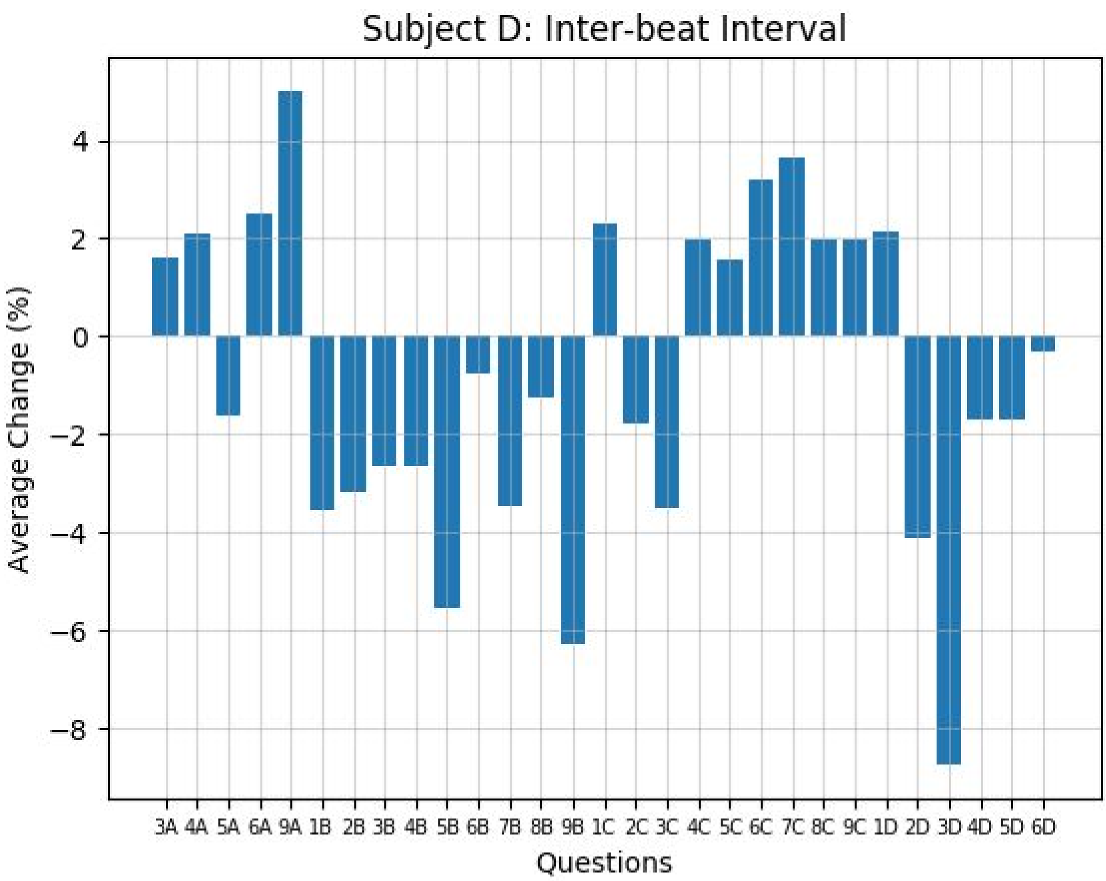


Figure 7(c). Change in IBI for Subject D

Based on Figure 7(c), we can examine the questions that induced significant (~2% and above) increases in IBI when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: $41 [2], cash, check [2], mailbox, envelope 1, office, envelope 4, mailroom,

Total Keyword Count: check [8], $41 [4], $470.16 [3], cash [3], mailroom [3], mailbox [3], envelope 2 [2], envelope 4 [2], envelope 1 [2], bag

Subject E

Based on Figure 8(a), we can examine the questions that induced significant (~10% and above) increases in EDA when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: check [2], cash, $41, mailroom, envelope 2, pockets

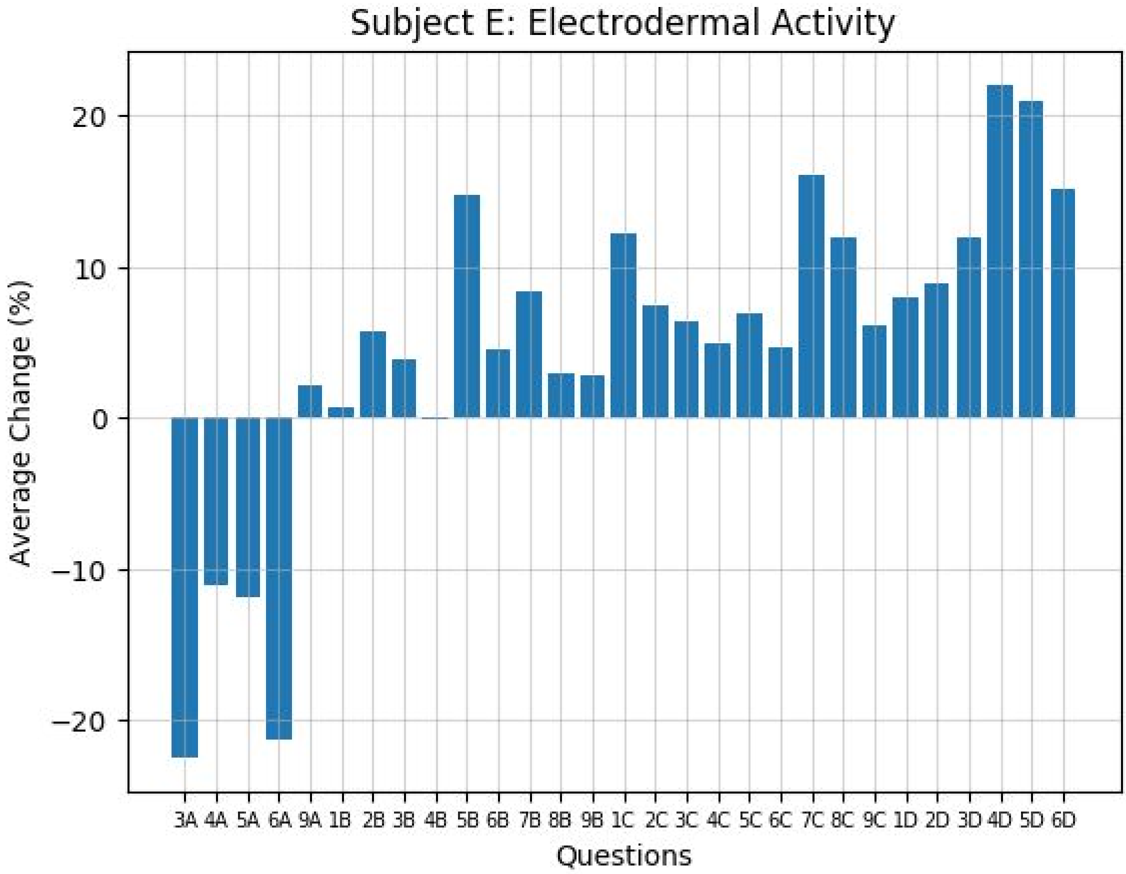


Figure 8(a). Change in EDA for Subject E

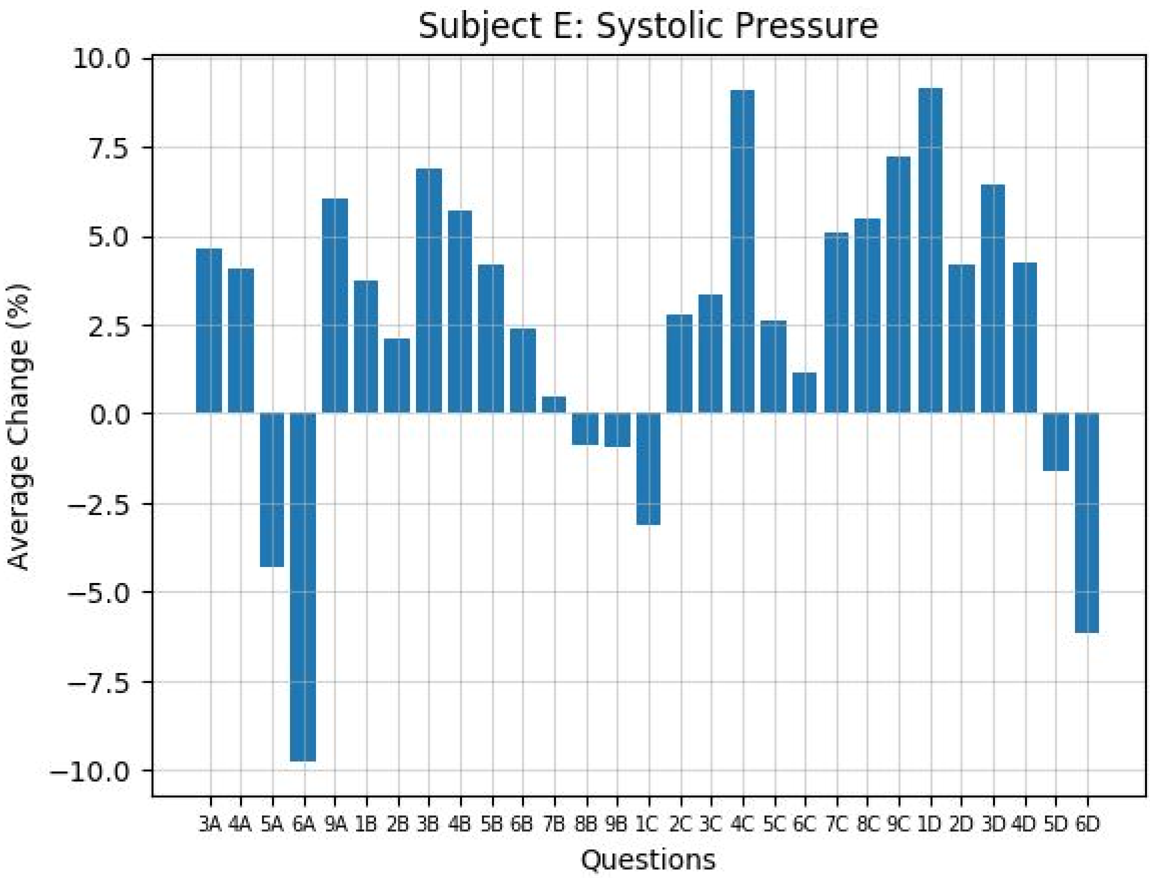


Figure 8(b). Change in systolic BP for Subject E

Based on Figure 8(b), we can examine the questions that induced significant (~2.5% and above) increases in systolic BP when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: check [2], envelope 1 [2], mailroom, mailbox, $470.16, office, pockets, bag

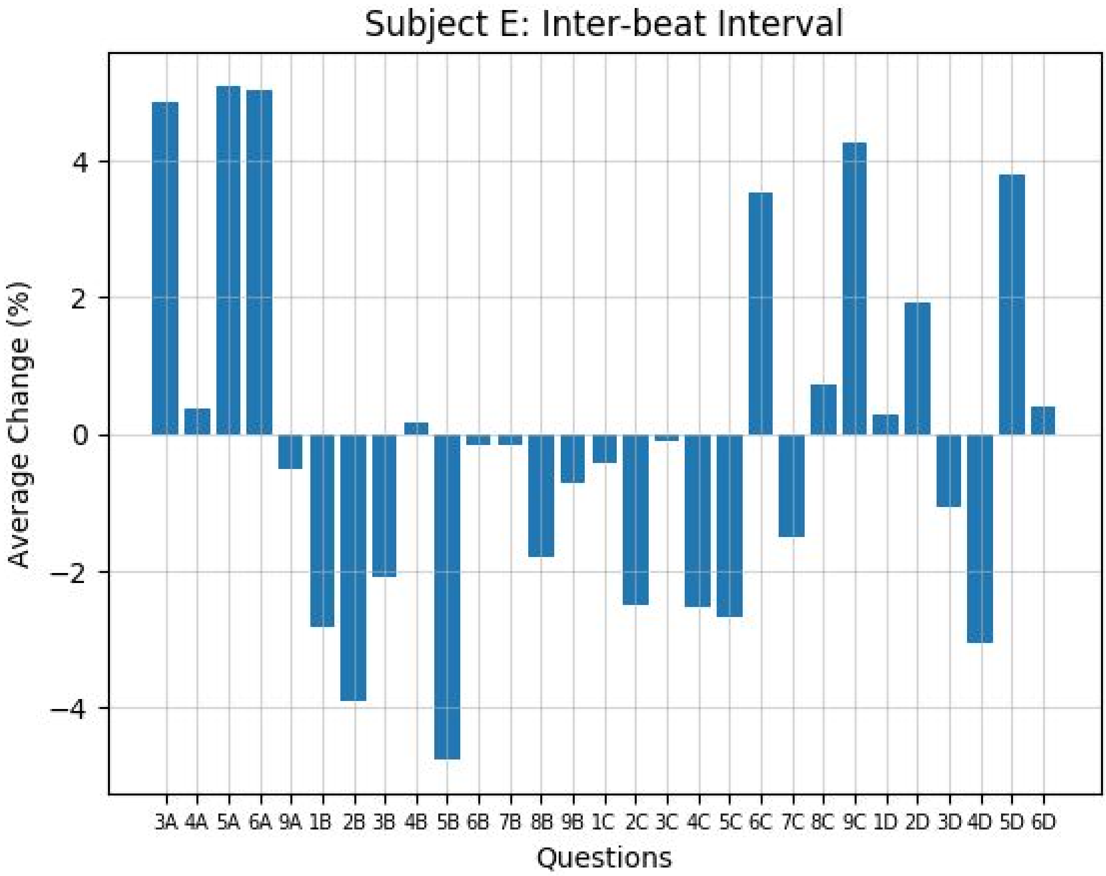


Figure 8(c). Change in IBI for Subject E

Based on Figure 8(c), we can examine the questions that induced significant (~2% and above) increases in IBI when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: cash [5], mailbox [2], bag [2], $41 [2], mailroom, office, $470.16, envelope 1, envelope 3

Total Keyword Count: cash [6], check [4], mailbox [3], bag [3], $41 [3], mailroom [3], envelope 1 [3], office [2], $470.16 [2], pockets [2], envelope 3, bag, envelope 2

Subject F

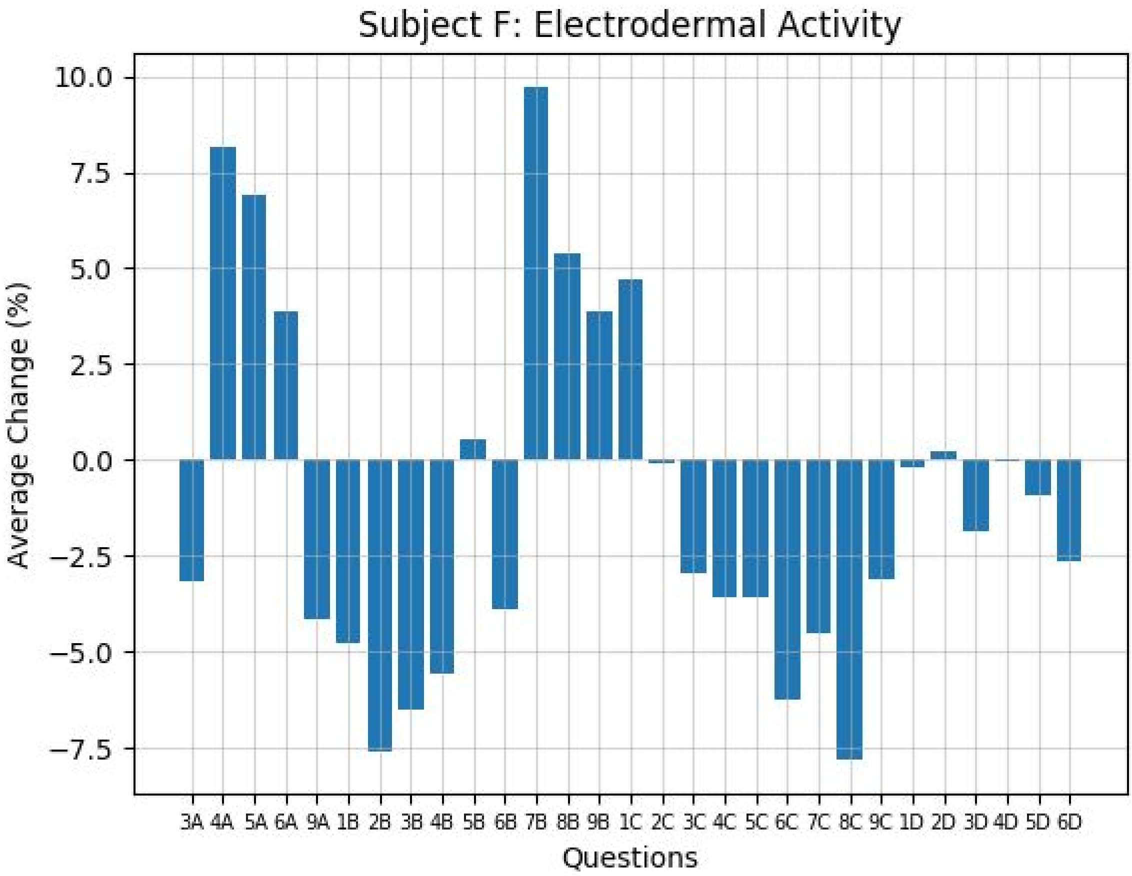


Figure 9(a). Change in EDA for Subject F

Based on Figure 9(a), we can examine the questions that induced significant (~2.5% and above) increases in EDA when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: cash [4], $41, $470.16, envelope 2

Based on Figure 9(b), we can examine the questions that induced significant (~2.5% and above) increases in systolic BP when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: cash [4], mailbox [2], $470.16, $41, check, envelope 2, office, pockets

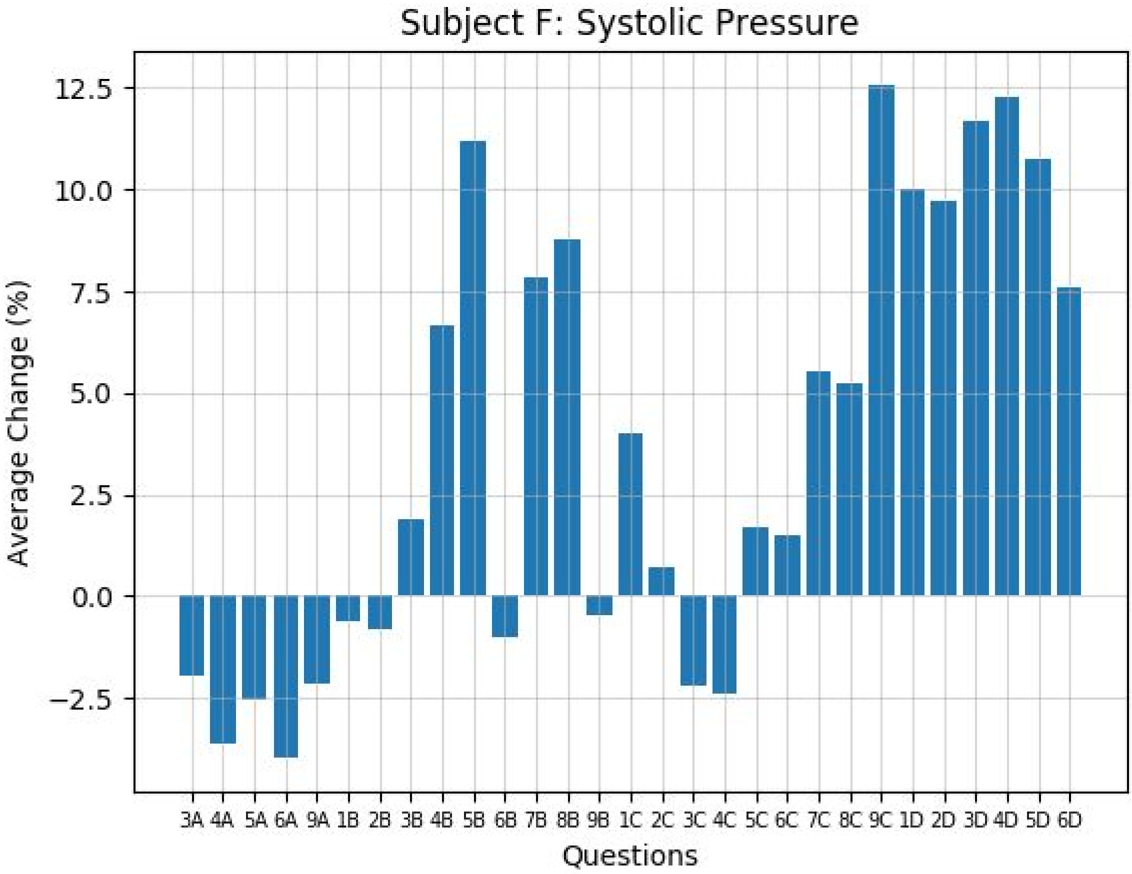


Figure 9(b). Change in systolic BP for Subject F

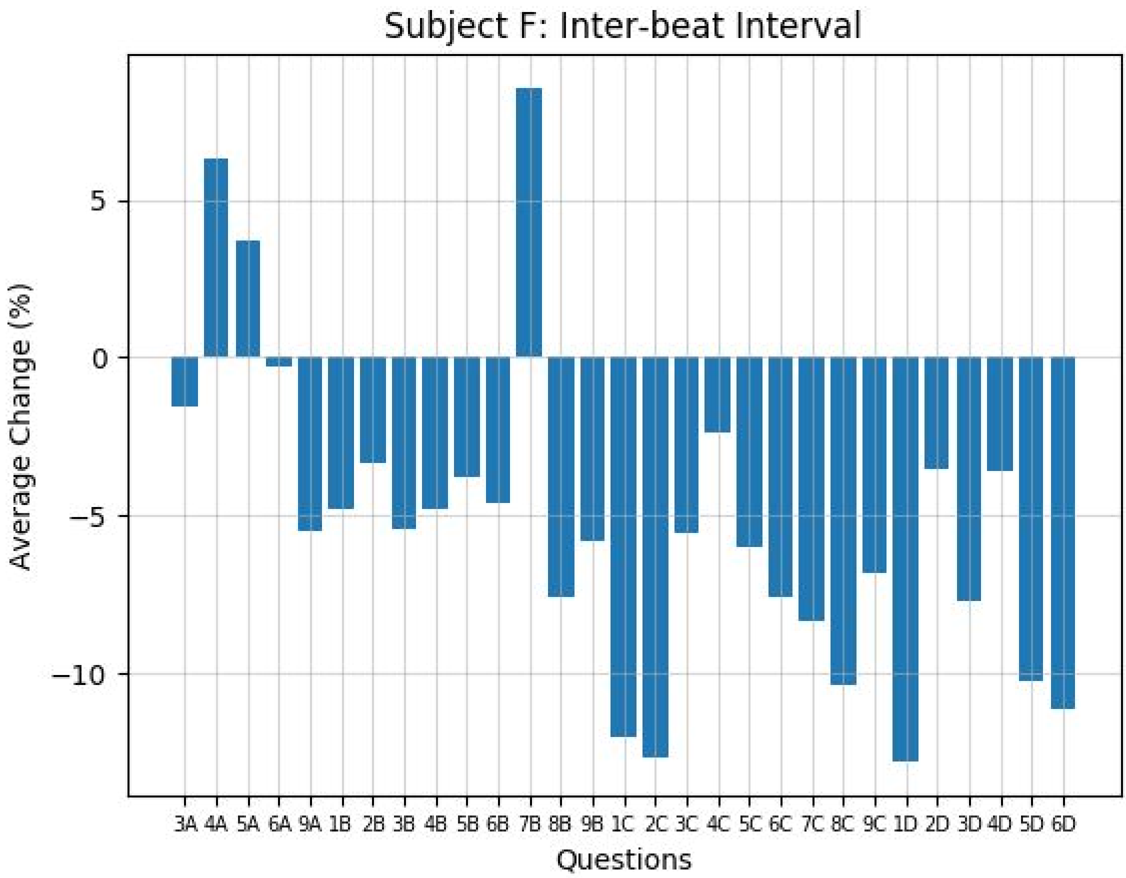


Figure 9(c). Change in IBI for Subject F

Based on Figure 9(c), we can examine the questions that induced significant (~5% and above) increases in IBI when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: cash [3], $470.16 [2], mailroom, office, check, envelope 2

Total Keyword Count: cash [11], $470.16 [4], envelope 2 [4], mailbox [2], $41 [2], check [2], office [2], pockets, mailroom

<u>Subject G</u>

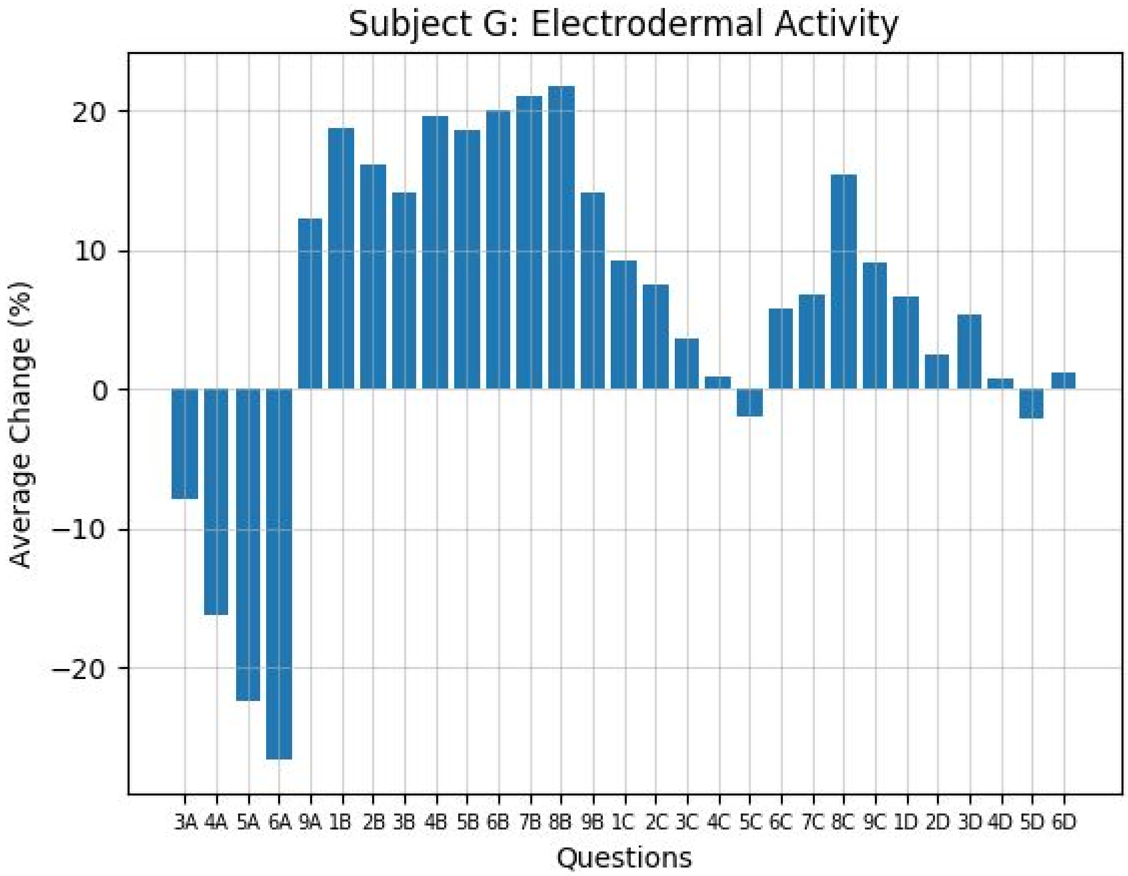


Figure 10(a). Change in EDA for Subject G

Based on Figure 10(a), we can examine the questions that induced significant (~10% and above) increases in EDA when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: mailroom [2], envelope 1, cash, bag

Based on Figure 10(b), we can examine the questions that induced significant (~2% and above) increases in systolic BP when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: mailroom [2], envelope 1 [2], cash [2], check [2], mailbox, office [2], envelope 2, bag [2], $41, $470.16

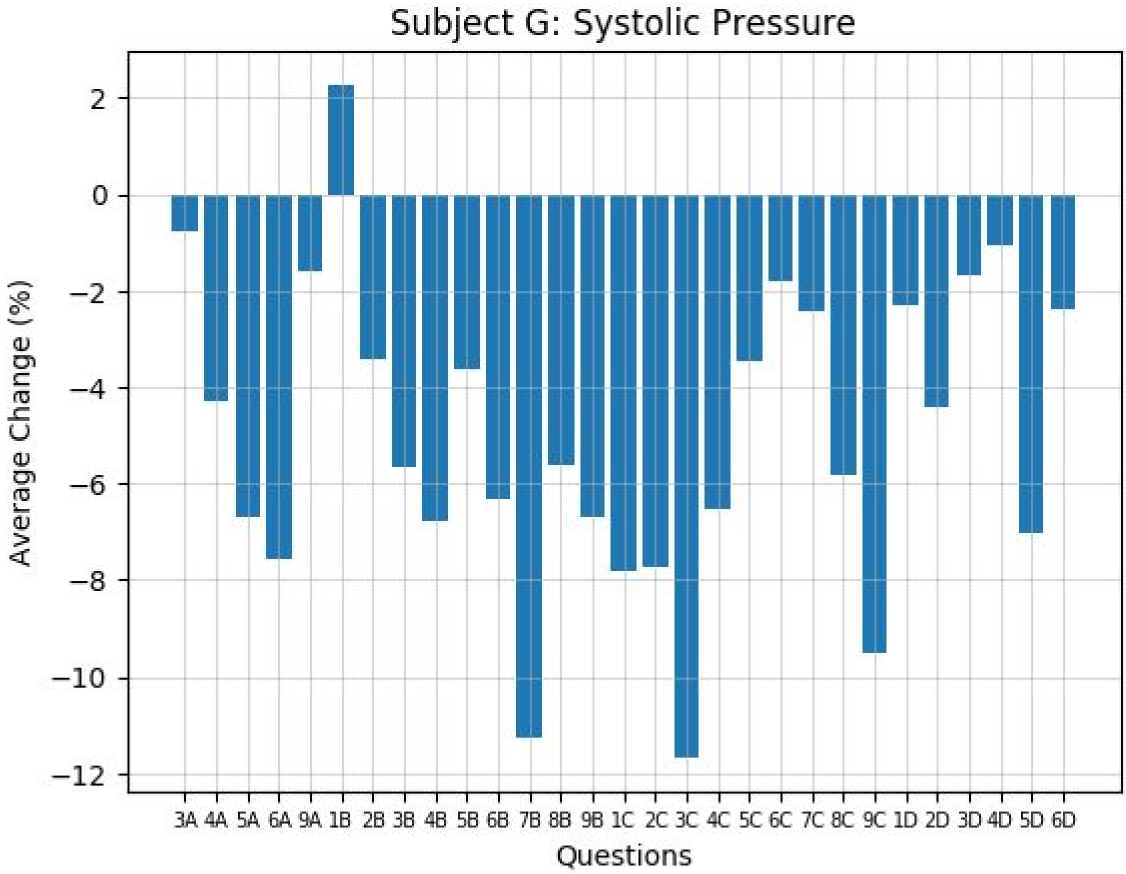


Figure 10(b). Change in systolic BP for Subject G

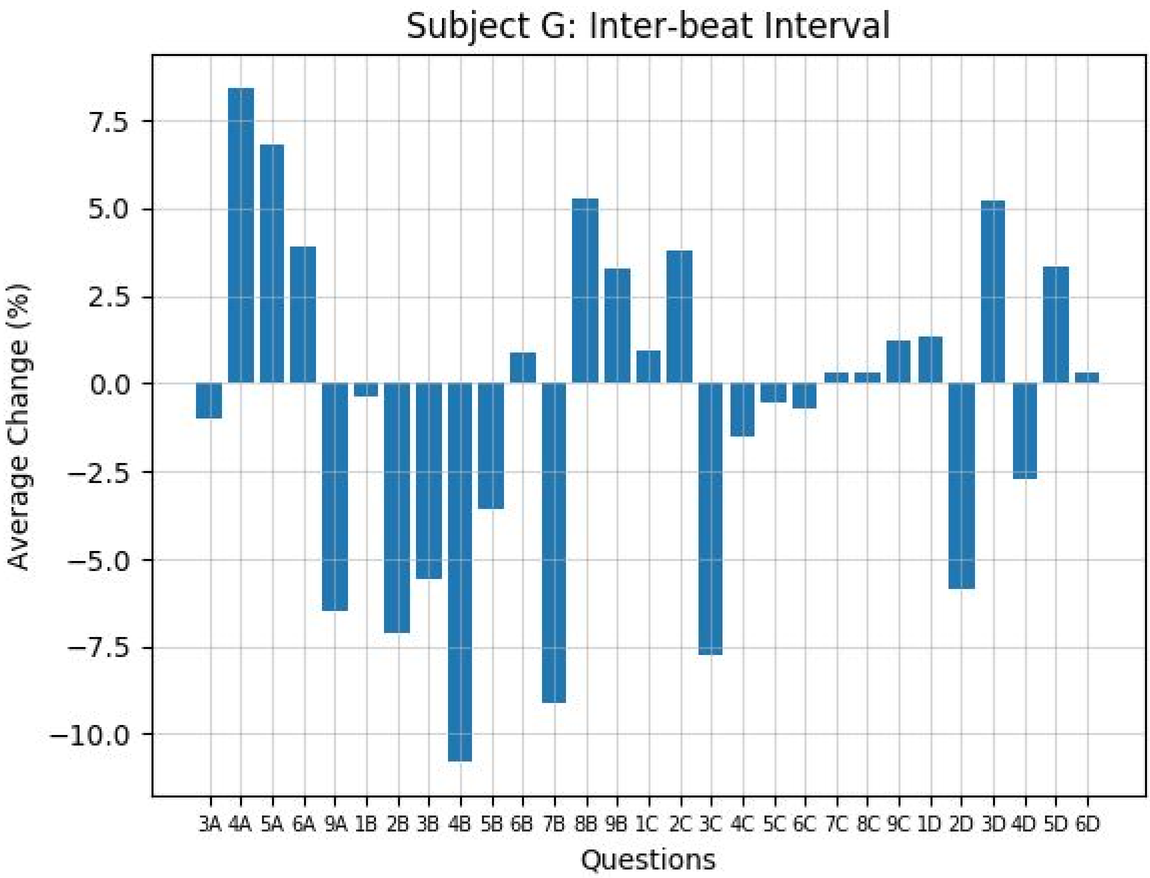


Figure 10(c). Change in IBI for Subject G

Based on Figure 10(c), we can examine the questions that induced significant (~2.5% and above) increases in IBI when compared to the preceding change and note down a list of keywords present in the relevant questions.

Keyword Count: check [3], envelope 1 [2], cash [2], mailroom, envelope 2, $41 [2], mailbox, $470.16, office, bag

Total Keyword Count: mailroom [5], envelope 1 [5], cash [5], check [5], bag [4], office [3], $41 [3], envelope 2 [2], $470.16 [2], mailbox [2]

<u>Evaluation of Keyword Count</u>

By aggregating the Total Keyword Count for each subject, we can arrive at a composite table.

Subject	Check	Cash	$470.16	$41	Mailroom	Mailbox	Office	Bag	Pockets	Envelope 1	Envelope 2	Envelope 3	Envelope 4
A	3	5	3	2	3	3	1	2	0	1	2	0	0
B	2	8	2	1	5	1	2	3	1	1	1	0	0
C	2	8	3	3	3	1	3	3	1	3	2	0	1
D	8	3	3	4	3	3	0	1	0	2	2	0	2
E	4	6	2	3	3	3	2	1	2	3	1	1	0
F	2	11	4	2	1	2	2	0	1	0	4	0	0
G	5	5	2	3	5	2	3	4	0	5	2	0	0

Table 2. Aggregation of Total Keyword Counts

Since the two characteristics of the crime we eventually wish to deduce are the location and the monetary form, we can further summarize Table 2 by summing the counts for associated words. Therefore, the monetary forms are summed with their respective dollar amounts, and the 'Mailroom' and 'Mailbox' columns are composited as well. Since the terms 'Office', 'Bag', and 'Pockets' are interdependent, we sum these columns as well. Finally, we subtract a point for questions that are equivalent to one count despite being previously counted as two. For example, a question about whether the subject took a check worth $470.16 is no longer considered to feature two distinct keywords ('check' and '$470.16') and now serves as a single count for the 'Check' column, since the all checks in the experiment were for $470.16.

Subject	Check	Cash	Mailroom	Office	Envelope 1	Envelope 2	Envelope 3	Envelope 4
A	6	6	6	3	1	2	0	0
B	4	8	6	6	1	1	0	0
C	5	8	4	7	3	2	0	1
D	9	6	6	1	2	2	0	2
E	5	8	6	5	3	1	1	0
F	6	12	3	3	0	4	0	0
G	6	6	7	7	5	2	0	0

Table 3. Summarized table of Keyword Counts

We can now make inferences about individual subjects. According to Table 3, it is likely that Subject A entered the **mailroom** during his crime. However, we cannot say with any certainty whether he stole a check or cash since the counts are the same. The initial envelope number indicators are not conclusive either.

Subject B appears to have a strong response to questions relevant to **cash**, and can, therefore, be considered a candidate for the same. However, no other conclusions can be drawn.

Subject C seems to have stolen **cash** and to have entered the **office**.

The values generated by the analysis of Subject D seems to indicate conclusively that he entered the **mailroom** during his crime, and that he stole a **check.**

It is difficult to make inferences about Subject E. Although it appears that he stole cash, he also may have begun the crime with Envelope 1, which mandates the theft of a check. Therefore, no conclusion can be drawn.

Subject F shows strong indicators of having stolen **cash** and having begun the crime with Envelope 2. Since **Envelope 2** directs the reader to steal cash from the mailbox, we can conclude that Subject F did so.

Subject G provides no indication of the particulars of his crime except for an inconclusively greater differential response to questions about Envelope 1, which requires the reader to steal a check from the mailbox.

At this stage, we can populate portions of Table 1.

	Check	**Cash**	**Subjects**
Mailbox	Envelope 1: D	Envelope 2: F	**3 = {F, D, A}**
Office	Envelope 3	Envelope 4: C, B	**4 = {C, B, E, G}**
Subjects	**3 = {D, ?, ?}**	**4 = {F, C, B, ?}**	**7 = {A, B, C, D, E, F, G)}**

Table 4. Semi-populated table of inferences

We begin by placing Subject F in the cell for Envelope 2 since the evidence is conclusive. Since we have inferred that Subject D entered the mailroom to steal a check, we place the subject in the corresponding box as well. Subject C appears to have stolen cash from the office, and is placed at the respective intersection.

Now we can begin to consider the conclusive evidence for each subject. Subject A appears to have entered the mailroom, and can therefore be placed in the sum for the respective row. We can also conclude that Subject B stole cash, and can similarly be placed at the bottom of the ‘Cash’ column. The data on Subjects E and G is inconclusive, but since we know that the 3 individuals who went to mailbox have been identified, Subjects E and G must have gone to the office. The position of Subject B in the table can also be deduced in a similar manner.

Thus, we are left with three questions to answer via further analysis of the raw waveforms:

1. Did Subject A steal cash or a check from the mailbox?
2. Did Subject E steal cash or a check from the office?
3. Did Subject G steal cash or a check from the office?

To answer the first question, we examine the time segment for Subject A featuring questions about the mailbox. By examining Figure 11, we can look for sudden changes in response to questions about the money stolen.

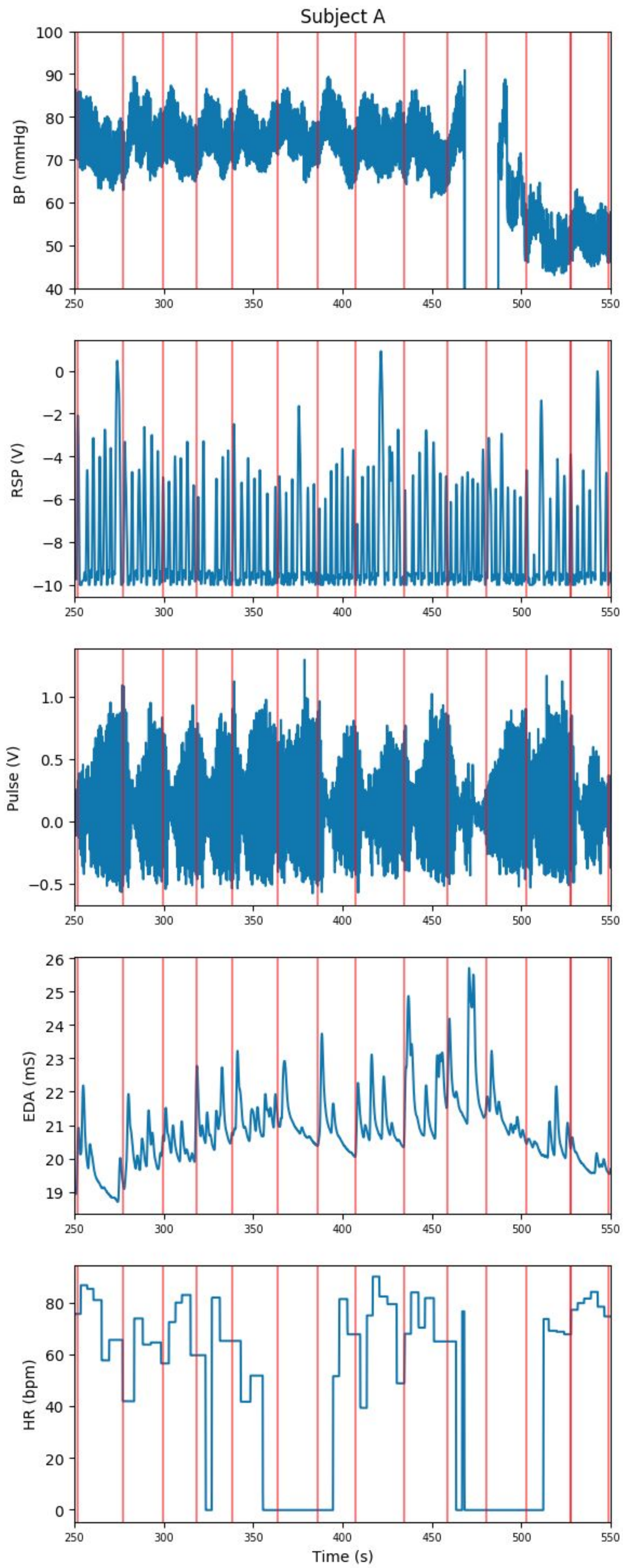


Figure 11. Subject A's responses to questions about the mailroom

A visual inspection of the graph offers little improvement on the existing data. While the overall downward trend in BP prevents a reliable reading, we can observe a slight increase in pulse amplitude for 9B, which mentions a check. Thus, we can tentatively assign A to the 'check' column.

Next, we consider the data for Subject E over the period featuring questions about the office.

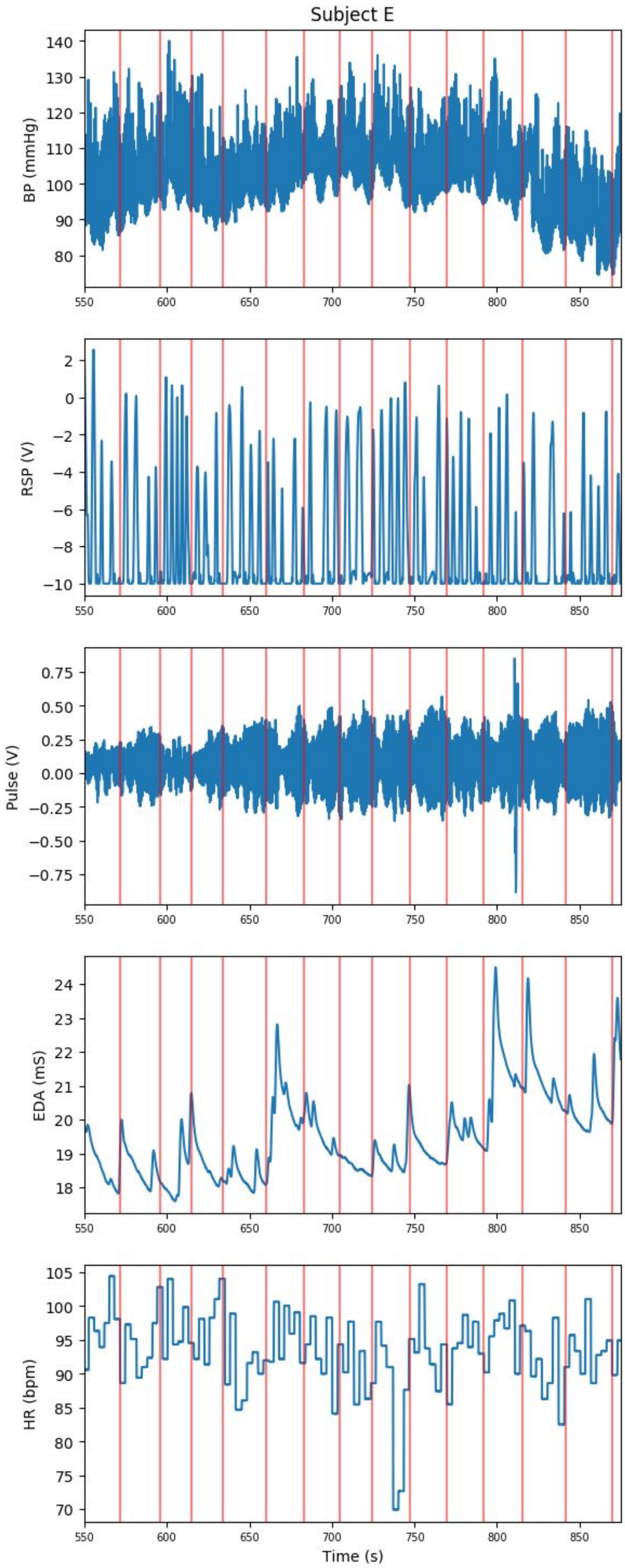


Figure 12. Subject E's responses to questions about the office

Since the only question remaining is the item(s) stolen, we can directly examine the responses for question 8C versus 3D, and 1D (which refer to the monetary medium) versus 6D (which refer to the dollar amount). Responses for 8C include an increase in BPM, a slight increase in EDA, and an increase in RSP. 3D elicits a slight increase in EDA. 1D prompts an increase in BPM, a slight increase in EDA, an increase in BP, and a rise in RSP. In comparison, 6D leads to a slight increase in BPM. We can, therefore, infer that questions 8C and 1D (which both mention 'cash') are more relevant than their counterparts that mention checks. Hence, we conclude that Subject E stole cash.

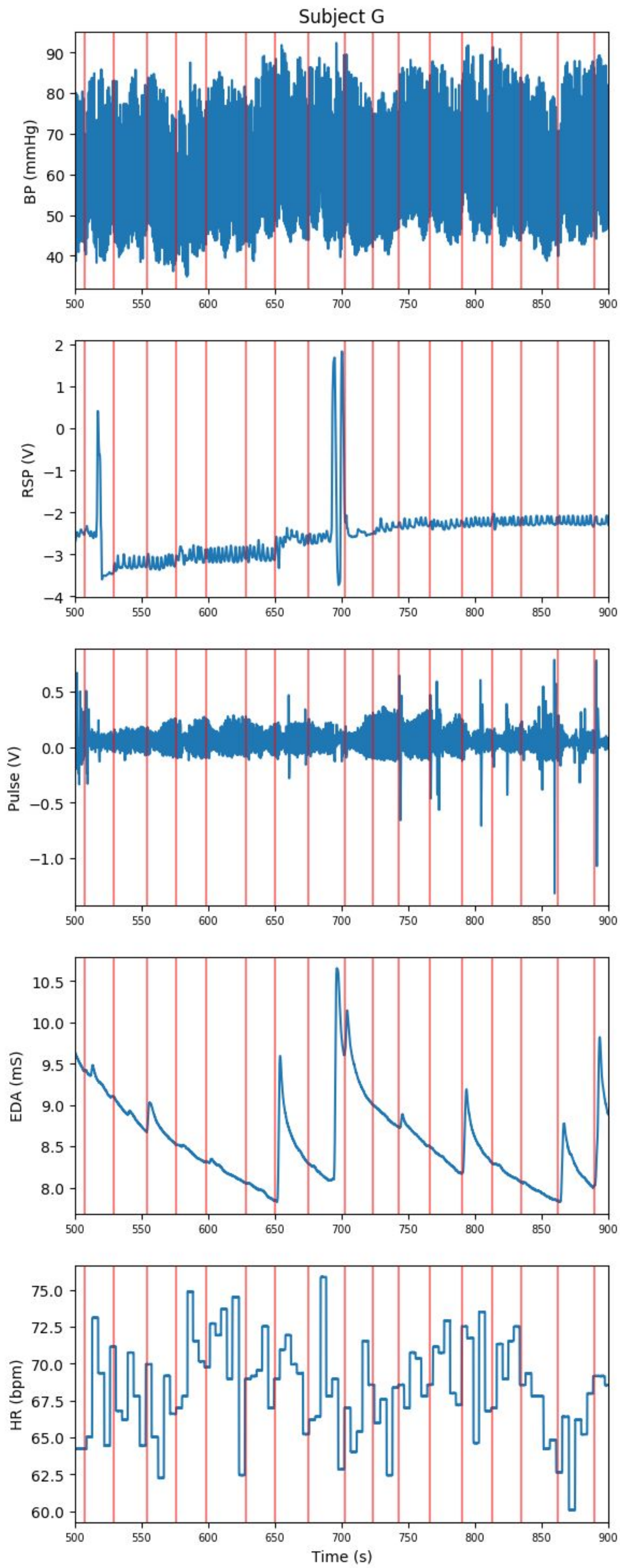


Figure 13. Subject G's responses to questions about the office

We perform the same evaluation as we did for Subject E. Responses for 8C include a slight increase in BPM and EDA. 3D leads to an increase in EDA and an increase in BP. 1D prompts a slight increase in BPM, a large increase in pulse amplitude and a slight increase in BP. 6D elicits a slight increase in BP, an increase in EDA, and an increase in BP.

Due to the seemingly indiscriminate rise in various parameters in response to different questions, no reasonable inference can be made. By inspecting the graph visually, we can see substantial spikes in RSP, EDA, and BP just before the 700-second mark, seemingly without a stimulus. Therefore, a visual inspection yields no insights.

As a last resort, we fill in the previous table by eliminating the other choices once Subject E is assigned a position. Due to Subject E's assignment, all available spots in the 'Cash' column are occupied, leaving only the 'Check' column for both Subject A and Subject G. We now have our final assignments.

	Check	**Cash**	**Subjects**
Mailbox	D, A	F	**3 = {F, D, A}**
Office	G	C, B, E	**4 = {C, B, E, G}**
Subjects	**3 = {D, A, G}**	**4 = {F, C, B, E}**	**7 = {A, B, C, D, E, F, G)}**

Table 4. Final table of inferences

In conclusion, our deductions are as follows:

- Subject A stole a check from the mailroom.
- Subject B stole cash from the office.
- Subject C stole cash from the office.
- Subject D stole a check from the mailroom.
- Subject E stole cash from the office.
- Subject F stole cash from the mailroom.
- Subject G stole a check from the office.

Discussion

Evaluation of Methods Used

Although the inferences in this report are based on physiological data and deduction, there are certain shortcomings in the methods employed.

1. By taking the average over the entire period between questions, we lose the immediate orienting response to questions that may provide us with valuable information. While the response calculations utilized provide us with data about significant sustained changes, the orienting response would aid the evaluation process.

2. Visual inspections of the signals were carried out without quantification, i.e., by examining the signal segment as a whole and estimating the benchmark for 'significant' changes, instead of comparing their magnitudes of change in numerical terms. It would be more useful to measure the changes with a uniform metric.

3. General trends were not considered in the study. While the overall gradual decrease in blood pressure was considered for certain subjects, they may be similar trends in other signals, such as a continuously increasing EDA that provides the illusion of an increase in response to a particular question.

4. The precision of beat detections from photoplethysmographic recordings is lower than electrocardiogram recordings, and cannot be discounted when comparing IBI changes [3].

5. The effect of habituation was not considered. Questions about envelopes, for example, were repeated. It would stand to reason that the initial question may elicit a response to the novelty of a new question, while the following three questions would result in progressively less significant responses, making it difficult to infer whether the first response was the result of guilty knowledge or merely novelty.

For these reasons, it would be impractical to be sure about the inferences. However, the results from the keyword evaluations that allowed us to infer the crimes of certain subjects without having to resort to logical deductions with the help of the table may be viable.

Possible improvements to the methods utilized above would include automating keyword analysis, and perhaps observing the response to questions at a higher resolution of time to observe the words or phrases in the question that induce the response. This would, however, also require the time-stamps for individual words or phrases in the sentence and could best be achieved by recording and calibrating the 'interrogation' process. Taking this concept a step further, we could, for example, consider questions about the dollar amounts featuring the phrases '$41' and '$470.16'. Any change in parameters during the mention of the initial syllable 'four' could help us infer that the resultant difference is reflective of the syllable 'four', rather than the dollar amount or the question as a whole.

Consistency in Literature

Amongst the chosen parameters, the greatest consensus on efficacy was associated with EDA. In particular, Podlesny and Raskin (1977) found that 'virtually no reported experiment has failed to find significant discrimination between truth and deception' using the measure [2]. In his review of electrodermal measures, Rosenfeld (2018) described the results as 'consistent' [3].

Academic consensus was found to be slightly less consistent on heart rate as an indicator of deception. Podlesny and Raskin (1977) found that Barland and Raskin (1975) conducted the best laboratory tests amongst the studies they examined, and that the study found correlations between heart rate deceleration and deception [2, 4]. However, Hira and Furumitsu (2009) found that heart rate acceleration was a better indicator. Notwithstanding their study, deceleration has been more broadly accepted as a sign of deception [8, 9].

Despite being explored in several studies, the validity of blood pressure as an indicator has failed to generate as much consensus as the previously mentioned parameters. While discussing several studies of deception that reported high rates of accuracy using blood pressure measurements, Podlesny and Raskin (1977) were critical of the methods and paradigms used in these studies, which may render the findings less valid [2]. Moreover, Reid (1945) found that typical blood pressure responses of deception can be artificially produced by muscle movements [5]. The lack of consensus on the time necessary for a maximum rise in systolic pressure following a stimulus compounds the problem of confirming the validity of blood pressure as a measure of deception [6].

Physiological Processes

The underlying physiological processes associated with the parameters used in the study can be summarized as follows:

1. Heart Rate: The sympathetic and parasympathetic nervous systems modulates heart rate, with the latter capable of a greater dynamic range of control [3].

2. Blood Pressure: As mentioned previously, arterial tension induced by the pressure caused by moving blood is responsible for blood pressure [5]. Vascular smooth muscles also contribute to blood pressure regulation under the control of the sympathetic nervous system [3].

3. Respiration: Respiration is modulated by the interplay of central and vagal circuits as well as peripheral feedback loops, and can be under voluntary control [3].

Signal Processing

As discussed previously, downsampling was the only pre-processing used in this study's methods since passing the signal through a low-pass filter offered no practical advantage. Since we knew the frequency of the biological signals utilized in this study, we could downsample the signal without concern. If warranted by the degree of noise corruption in a signal, one could feasibly use a band-pass filter to filter out noise with frequencies both above and below our expected range. However, the use of other biological signals, such as electrocardiograms, would warrant a higher sampling frequency to capture all the characteristics of the waveform.

Conclusion

By leveraging the considerable body of literature addressing the validity of polygraph examinations, we were able to generate graphical and tabular visualizations to analyze the differential responses over the period of questioning. In order to draw conclusions based on the data without resorting to subjective measures, a keyword-centric approach was developed and adopted to aggregate and normalize responses that may be indicative of guilty knowledge. In certain cases, this approach led to inconclusive results, which were then further examined by analyzing individual questions of interest and their effect on the relevant waveform. Logical deduction was used to infer each subject's crime and draw conclusions about the same. Despite the possibility that our predictions may be incorrect, partly due to the reasons discussed, this report served as a practical introduction to the merits and inherent demerits of the polygraph test.

References

[1]W. Iacono, "Effective Policing", Criminal Justice and Behavior, vol. 35, no. 10, pp. 1295-1308, 2008.

[2]J. Podlesny and D. Raskin, "Physiological Measures and the Detection of Deception", Psychological Bulletin, vol. 84, no. 4, pp. 782-799, 1977.

[3]J. Rosenfeld, Detecting Concealed Information and Deception, 1st ed. Academic Press, 2018, pp. 12-15.

[4]G. Barland and D. Raskin, "An Evaluation of Field Techniques in Detection of Deception", Psychophysiology, vol. 12, no. 3, pp. 321-330, 1975.

[5]J. Reid, "Simulated Blood Pressure Responses in Lie-Detector Tests and a Method for Their Detection", Journal of Criminal Law and Criminology (1931-1951), vol. 36, no. 3, p. 201, 1945.

[6]M. Orne, R. Thackray and D. Paskewitz, "On the detection of deception: A model for the study of the physiological effects of psychological stimuli", in Handbook of Psychophysiology, N. Greenfield and R. Sternbach, Ed. New York: Holt, Rinehart and Winston, 1972, pp. 743-785.

[7]R. Arther, "Blood Pressure Rises on Relevant Questions in Lie Detection: Sometimes an Indication of Innocence Not Guilt", The Journal of Criminal Law, Criminology, and Police Science, vol. 46, no. 1, p. 112, 1955.

[8]S. Hira and I. Furumitsu, "Tonic Arousal During Field Polygraph Tests in Guilty vs. Innocent Suspects in Japan", Applied Psychophysiology and Biofeedback, vol. 34, no. 3, pp. 173-176, 2009.

[9]M. Gamer, "Cambridge University Press", in Memory Detection, 1st ed., V. Bruno, B. Gershon and M. Ewout, Ed. Cambridge: Cambridge University Press, 2011, pp. 27-45.

[10]M. Gamer, B. Verschuere, G. Crombez and G. Vossel, "Combining physiological measures in the detection of concealed information", Physiology & Behavior, vol. 95, no. 3, pp. 333-340, 2008.

Appendix: Code

```
"""
ENGR-E 599: Psychophysiological Engineering

Polygraph Project

@author: Vedang Narain

2 November 2018
"""

#================================================================================
#------------------------------------NOTES---------------------------------------
#================================================================================

"""
— This code evaluates one subject at a time.

- To change the subject, make edits to lines 188 and 189 (necessary), and lines
  254, 316, 317, and 318 (to change graph titles).

- To change the period of interest for quick viewing, make changes to lines 225
  and 226.

- To change the sampling rate, change line 199.

- To evaluate a particular question, use the functions.

— Acronyms: RIQ = Recent Irrelevant Questions
            IPP = Immediately Preceding Period
            HR = Heart Rate

— For best results, please view the graphs in the IPython console or the report.
"""

#================================================================================
#----------------------------------LIBRARIES-------------------------------------
#================================================================================

import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
from scipy import signal

#================================================================================
#----------------------------------FUNCTIONS-------------------------------------
#================================================================================

"""
Note: The functions below only accept inputs for relevant (non-control) questions.
      In other words, questions 1A, 2A, 7A, and 8A are used as baseline regions
      since they are definite lies, and should not be treated as relevant
      questions. Question 7D has been considered an irrelevant question as well.
      It is only used to mark the end of the response time for the preceding
      question.
```

```
"""

# define function for Butterworth Low-pass Filter
def butterworth_lpf(unfiltered_signal, cutoff_freq, order):
    nyq_freq = 0.5 * Fs
    normalized_cutoff = cutoff_freq/nyq_freq
    b, a = signal.butter(order, normalized_cutoff)
    filtered_signal = signal.filtfilt(b, a, unfiltered_signal)
    return filtered_signal


# define function to add event separators
def separators():
    for i in event_times:
        if i < end_time:
            plt.axvline(x = i, color = 'red', alpha = 0.5)


# define function to calculate simple 5-second IPP baseline (unused)
def simple_ipp_baseline(parameter, event_row):  # accepts (full_signal,
row_number_of_question_in_events_file)
    event_index = int(Fs * event_times[event_row - 2])
    return np.mean(parameter[event_index - (4 * Fs) : event_index + 1])


# define function to generate start and end indices for RIQ baseline
def get_riq_indices(event_row):  # accepts (row_of_question_in_events_file)
    if 6 < event_row < 11:
        start_index = int(Fs * event_times[3])
        end_index = int(Fs * event_times[5])
    elif 12 < event_row < 38:
        start_index = int(Fs * event_times[9])
        end_index = int(Fs * event_times[11])
    return start_index, end_index


# define function to calculate simple RIQ baseline (use only for EDA)
def riq_eda_baseline(event_row):  # accepts (row_of_question_in_events_file)
    start_index, end_index = get_riq_indices(event_row)
    return np.mean(full_skin[start_index : end_index])


# define function to calculate RIQ systolic baseline (use only for BP)
def riq_systolic_baseline(event_row):  # accepts (row_of_question_in_events_file)
    systolic_list_bp = []
    start_index, end_index = get_riq_indices(event_row)
    for i in peak_pos_bp:
        if start_index <= i <= end_index:
            systolic_bp = full_bp[i]
            systolic_list_bp.append(systolic_bp)
    return np.mean(systolic_list_bp)


# define function to calculate RIQ IBI baseline (use only for Pulse (PPG))
def riq_ibi_baseline(event_row):  # accepts (row_of_question_in_events_file)
    systolic_list_ppg = []
```

```
    interval_list_ppg = []
    cnt = 0
    start_index, end_index = get_riq_indices(event_row)
    for i in peak_pos_ppg:
        if start_index <= i <= end_index:
            systolic_list_ppg.append(i)
    while (cnt < len(systolic_list_ppg) - 1):
        interval = ((systolic_list_ppg[cnt + 1] - systolic_list_ppg[cnt])) / Fs
        interval_list_ppg.append(interval)
        cnt += 1
    return np.mean(interval_list_ppg)


# define function to generate start and end indices for question segment of interest
def get_question_indices(event_row):  # accepts (row_of_question_in_events_file)
    start_index = int(Fs * event_times[event_row - 2])
    end_index = int(Fs * event_times[event_row - 1])
    return start_index, end_index


# define function to calculate simple average (use only for EDA)
def average_eda(event_row):  # accepts (row_of_question_in_events_file)
    start_index, end_index = get_question_indices(event_row)
    return np.mean(full_skin[start_index : end_index])


# define function to calculate systolic average (use only for BP)
def average_systolic(event_row):  # accepts (row_of_question_in_events_file)
    systolic_list_bp = []
    start_index, end_index = get_question_indices(event_row)
    for i in peak_pos_bp:
        if start_index <= i <= end_index:
            systolic_bp = full_bp[i]
            systolic_list_bp.append(systolic_bp)
    return np.mean(systolic_list_bp)


# define function to calculate average IBI (use only for Pulse (PPG))
def average_ibi(event_row):  # accepts (row_of_question_in_events_file)
    systolic_list_ppg = []
    interval_list_ppg = []
    cnt = 0
    start_index, end_index = get_question_indices(event_row)
    for i in peak_pos_ppg:
        if start_index <= i <= end_index:
            systolic_list_ppg.append(i)
    while (cnt < len(systolic_list_ppg) - 1):
        interval = ((systolic_list_ppg[cnt + 1] - systolic_list_ppg[cnt])) / Fs
        interval_list_ppg.append(interval)
        cnt += 1
    return np.mean(interval_list_ppg)


# define function to calculate and quantify percentage change from RIQ baseline
def baseline_change(event_row):  # accepts (row_of_question_in_events_file)
    eda_change = ((average_eda(event_row) / riq_eda_baseline(event_row)) * 100) - 100
```

```
    systolic_change = ((average_systolic(event_row) / riq_systolic_baseline(event_row)) * 
100) - 100
    ibi_change = ((average_ibi(event_row) / riq_ibi_baseline(event_row)) * 100) - 100
    return (eda_change, systolic_change, ibi_change)


# define function to plot bar chart of responses relative to RIQ baseline
def bar_chart(plot_title, change_list):  # e.g. ('Subject A: EDA', eda_change_list)
    plt.figure()
    plt.rc('xtick', labelsize = 7)
    plt.bar(question_positions, change_list, align = 'center')
    plt.xticks(question_positions, question_names)
    plt.title(plot_title)
    plt.xlabel('Questions')
    plt.ylabel('Average Change (%)')
    plt.grid(True, alpha = 0.5)
    plt.show()

#===============================================================================
#-----------------------------IMPORT AND PREPARE DATA---------------------------
#===============================================================================

# import data for subject of choice
raw_data = pd.read_table('Subject G.txt', skiprows = 15)
raw_events = pd.read_excel('SubjectG_events.xlsx', skiprows = [38])

# remove extra row while retaining header
corrected_data = raw_data.reindex(raw_data.index.drop(0))

# isolate individual arrays from event table
event_times = raw_events.iloc[:, 0]
event_labels = raw_events.iloc[:, 1]

# choose sampling rate (from 10 Hz up to 1 kHz)
Fs = 10

# calculate downsampling factor
downsampling_factor = 1000/Fs

# import raw signals into individual arrays
raw_bp = corrected_data.iloc[:, 1].values  # Raw Blood Pressure (mmHg)
raw_rsp = corrected_data.iloc[:, 2].values  # RSP (V)
raw_ppg = corrected_data.iloc[:, 3].values  # PPG (V)
# raw_arterial = corrected_data.iloc[:, 4].values  # Mean Arterial Pressure (mmHg)
raw_bpm = corrected_data.iloc[:, 5].values  # Pulse (BPM)
raw_skin = corrected_data.iloc[:, 6].values  # EDA (mS)

# downsample all signals to chosen sampling frequency
full_bp = raw_bp[::int(downsampling_factor)]
full_rsp = raw_rsp[::int(downsampling_factor)]
full_ppg = raw_ppg[::int(downsampling_factor)]
# full_arterial = raw_arterial[::int(downsampling_factor)]
full_bpm = raw_bpm[::int(downsampling_factor)]
full_skin = raw_skin[::int(downsampling_factor)]

#===============================================================================
```

```
#--------------------------CROP SIGNAL FOR EXAMINATION-------------------------
#==============================================================================

# choose start and end times of segment to be analyzed (in seconds)
start_time = 0
end_time = 500

# convert minutes to samples
start_sample = start_time * Fs
end_sample = end_time * Fs

# crop segments of signals for graphs
bp = full_bp[start_sample:end_sample]  # Raw Blood Pressure (mmHg)
rsp = full_rsp[start_sample:end_sample]  # RSP (V)
ppg = full_ppg[start_sample:end_sample]  # PPG (V)
# arterial = full_arterial[start_sample:end_sample]  # Mean Arterial Pressure (mmHg)
bpm = full_bpm[start_sample:end_sample]  # Pulse (BPM)
skin = full_skin[start_sample:end_sample]  # EDA (mS)

# obtain number of data points
length = len(bp)

# prepare time array
time_axis = np.linspace(start_time, end_time, length)

#==============================================================================
#--------------PLOT PARAMETER SNAPSHOTS FOR CHOSEN TIME INTERVAL---------------
#==============================================================================

# plot parameter values for chosen time interval
plt.figure()
plt.subplot(5, 1, 1)
plt.plot(time_axis, bp)
plt.title('Subject G')
plt.xlim(start_time, end_time)
# plt.ylim(40, 100)  # Line can be unmuted for Subject A to exclude error signal from
graph.
separators()
plt.ylabel('BP (mmHg)')
plt.subplot(5, 1, 2)
plt.plot(time_axis, rsp)
plt.xlim(start_time, end_time)
separators()
plt.ylabel('RSP (V)')
plt.subplot(5, 1, 3)
plt.plot(time_axis, ppg)
plt.xlim(start_time, end_time)
separators()
plt.ylabel('Pulse (V)')
plt.subplot(5, 1, 4)
plt.plot(time_axis, skin)
plt.xlim(start_time, end_time)
separators()
plt.ylabel('EDA (mS)')
plt.subplot(5, 1, 5)
plt.plot(time_axis, bpm)
```

```
plt.xlim(start_time, end_time)
separators()
plt.xlabel('Time (s)')
plt.ylabel('HR (bpm)')
plt.subplots_adjust(top = 3)
plt.show()

#===============================================================================
#--------------------FIND PEAKS FOR PULSE AND BLOOD PRESSURE-------------------
#===============================================================================

# generate peak positions for blood pressure and pulse (0.5-second gap allows for HR of
120 bpm)
peak_pos_bp, _ = signal.find_peaks(full_bp, prominence = 5, distance = 0.5 * Fs)
peak_pos_ppg, _ = signal.find_peaks(full_ppg, distance = 0.5 * Fs)

#===============================================================================
#-----------------------------QUANTIFY RESPONSES-------------------------------
#===============================================================================

# initialize lists for lists of changes
eda_change_list = []
systolic_change_list = []
ibi_change_list = []

# generate lists of changes
for i in range(7, 38):
    if i in {11, 12}:
        continue
    eda_change, systolic_change, ibi_change = baseline_change(i)
    eda_change_list.append(eda_change)
    systolic_change_list.append(systolic_change)
    ibi_change_list.append(ibi_change)

# create list of question names and positions for bar charts
question_names = ('3A', '4A', '5A', '6A', '9A', '1B', '2B', '3B', '4B', '5B',
                  '6B', '7B', '8B', '9B', '1C', '2C', '3C', '4C', '5C', '6C',
                  '7C', '8C', '9C', '1D', '2D', '3D', '4D', '5D', '6D')
question_positions = np.arange(len(question_names))

# plot charts for EDA, BP, and HR changes
bar_chart('Subject G: Electrodermal Activity', eda_change_list)
bar_chart('Subject G: Systolic Pressure', systolic_change_list)
bar_chart('Subject G: Inter-beat Interval', ibi_change_list)
```