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Fuzzy Identification and Modeling of Common Caffeine-Containing Beverages Consumption on Blood Pressure

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Abstract: The aim of the present study was to determine the effect of moderate caffeine consumption on blood pressure, also, to construct a prediction model for blood pressure using fuzzy modeling. The blood pressure was measured for each participant at several times after drinking the beverages. An adaptive neuro-fuzzy inference system (ANFIS) was used to model and identify the systolic and diastolic of the blood pressure. Experimental validation runs were conducted to compare the measured values and the predicted ones. The final fuzzy-based FIS model for the systolic blood pressure was formed from 62 total number of parameters, 398 number of training data pairs and 32 number of fuzzy rules. The results showed that the validation was 90% modeling or prediction accuracy of systolic blood pressure. The final fuzzy-based FIS model for the diastolic blood pressure was formed from 190 total number of parameters, 398 number of training data pairs and 162 number of fuzzy rules. The results showed that the average validation was 85% modeling or prediction accuracy of diastolic blood pressure. Based on the analysis results, it was found that the prediction of the systolic and diastolic of the blood pressure based on the caffeine consumption by ANIFS is probable. This method may be used to provide a simple means for determining the blood pressure after consuming a certain amount of caffeine-containing beverages.

Key words: Fuzzy modeling, systolic blood pressure, diastolic blood pressure, caffeine consumption, caffeine-containing beverages

INTRODUCTION

A large number of people consume coffee on a daily basis and even small health effects of substances in coffee may have large public health consequences. High intake of caffeinated coffee may influence blood pressure (BP) (Noordzij *et al*., 2005) or the risk of coronary heart disease (Roberts *et al*., 2005). A single dose of caffeine of 200-250 mg, equivalent to 2-3 cups of coffee, has been shown to increase systolic BP by 3-14 mmHg and diastolic BP by 4-13 mmHg shortly after intake (Nurminen *et al*., 1999). Approximately 90% of the caffeine contained in a cup of coffee is cleared from the stomach within 20 min (Chvasta and Cooke, 1971) and peak plasma concentration is typically reached within approximately 40 to 60 min (Rall, 1990). Blood pressure is comparatively sensitive to caffeine. By antagonizing adenosine, which has generalized inhibitory functions, the effect of caffeine is broadly stimulatory (Carter *et al*., 1995; James, 2004; Higdon and Frei, 2006; Papaioannou *et al*., 2006). Caffeine and adenosine have similar molecular structures, caffeine has the potential to occupy adenosine receptor sites (especially A_1 and A_{2a}), thereby blocking the regulatory effects of adenosine in the cardiovascular and central nervous systems (Bush *et al*., 1989). It was found that caffeine does have implications for cardiovascular disease, its affect on BP would appear to be a key consideration (James, 2004). Acute BP elevations in the range of 5 to 15 mm Hg systolic and 5 to 10 mm Hg diastolic are typical after experimental administration of caffeine in amounts comparable to those consumed in everyday life (Lane and Williams, 1985). The magnitude of BP elevations induced by each successive portion of caffeine beverage is approximately inversely proportional to the number of portions already consumed that day (Goldstein *et al*., 1990). That is, for the individual consumer, second and later cups of a caffeine beverage produce less hemodynamic reactivity than the initial cup of the day (Smits *et al*., 1985).

Modling and identification of food properties and processing has been the subject of many researchers in the food engineering field. Perrot *et al*. (2003) presented a hybrid approach based on fuzzy logic and genetic algorithms to control a crossflow microfiltration pilot plant. The results of simulations and pilot tests showed that it becomes possible to impose dynamics to the process that leads to maintain the state variable at a given reference. Tsourveloudis and Kiralakis (2002) applied a rotary drying process to olive stones. They described and modeled the process using fuzzy and

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neuro-fuzzy techniques based on available expertise and knowledge for a given, industrial size, rotary dryer. They also used ANFIS controller based on data taken from an empirical model of the dryer under study. Samhouri *et al.* (2007) found that the neuro-fuzzy modeling technique (i.e., adaptive neuro-fuzzy inference system [ANFIS]) can be used to achieve very satisfactory prediction accuracy (about 98%) in a model color mayonnaise system. Also, very satisfactory prediction accuracy (about 96%) was achieved by applying the neuro-fuzzy modeling technique (i.e., ANFIS) in predicting the emulsion stability and viscosity of a gum-protein emulsifier in a model mayonnaise system (Abu Ghoush *et al.*, 2008).

Despite extensive evidence of a direct causal relationship between dietary caffeine and elevated blood pressure, caffeine consumption continues to receive relatively little systematic clinical and public health attention.

No previous studies were done to recommend the caffeine level that may be consumed and to construct a prediction model for blood pressure using fuzzy modeling. Therefore, our aims in this study are to determine the effect of moderate caffeine consumption (1 cup from each caffeine containing beverages) on blood pressure. Also, to construct a prediction model for blood pressure using fuzzy modeling.

MATERIALS AND METHODS

Research design: Four different types of beverages were used in this study (to determine their acute effects on blood pressure. These drinks included Pepsi, Nescafe, Red Bull and Turkish coffee at a dose equivalent to the standard measures. The concentrations of the caffeine on these drinks were 38, 40, 80 and 150 mg/oz, respectively as determined by previous analysis (AOAC, 1980). Water matches to the drinks for caffeine content and pure water was used as a control. Latin square design was used to assess the effects of these beverages consumption on fifty six participants.

Research procedure

Subjects: Fifty Six participants healthy male and female with ages between 25-50 years with BMI <25 were recruited. Subjects were selected from the general population according to their response to an advertisement. The volunteers were asked to complete a screening questionnaire. Exclusions criteria were: smoking and having stopped smoking within the past 6 months; heavy tea and coffee drinking; taking medication or any supplements; a history of major illness such as diabetes, heart disease, liver disease and renal disease. There were 5 clinic visits during the study. At least 1 visit/week at the same day and time from each week was required from every subject. Subjects drank 1 standard cup from each drink type/visit. The subjects were asked not to drink or eat anything at least 12 h before attending to the clinic for blood pressure measurements.

Blood pressure measurements: Standard traditional recipes were used in this study for the drinks preparation. Blood pressure measurements were taken before each drink, 30, 45 and 60 min after completing the drink. Three measurements were obtained and the mean value of systolic (SBP) and diastolic pressure (DBP) were calculated and used in the analysis.

Statistical analysis: Data were analyzed by the Analysis of Variance procedure (ANOVA) by using SAS software (version 6.12, SAS Institute, Cary, NC) to evaluate the changes over time in variables measured at all trials (Turkish Coffee, NESCAFE, Red Bull, Pepsi). Comparison between treatments were analyzed using Fishers Least Significant Difference (LSD). In the analysis of variance, alpha level of 5% were used to test the null hypothesis.

Fuzzy modeling of output properties: Adaptive neuro-fuzzy inference system (ANFIS) is a fuzzy inference system implemented in the framework of an adaptive neural network. ANFIS is more powerful than the simple fuzzy logic algorithm and neural networks, since it provides a method for fuzzy modeling to learn information about the data set, in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data (Jang, 1993). In this study, the application of ANFIS to model and predict the output properties for the beverage-containing caffeine consumption were done. ANFIS modeling and prediction of output properties of caffeine beverage consumption system starts by obtaining a data set (input-output data points) and dividing it into training and validating data sets. Basically, an adaptive neuro-fuzzy inference system (ANFIS) was used to model and identify the systolic and diastolic of the blood pressure, with caffeine concentration, time after consumption, age, weight, height and ratios.

ANFIS applies two techniques in updating parameters. For premise parameters that define membership functions, ANFIS employs gradient descent back-propagation neural networks to fine-tune them. For consequent parameters that define the coefficient of each output equation, ANFIS uses that least squares method to identify them. This approach is called the hybrid learning method. More specifically, in the forward pass of the hybrid learning method, functional signals go forward until the consequent parameters are identified by the least square estimate. In the backward pass, the error rates propagate backward and the premise parameters are updated by the gradient descent.

ANFIS modeling and prediction of output properties (i.e., the systolic and diastolic of the blood pressure) starts by obtaining a data set (input-output data points) and dividing it into training and validating data sets. Each input/output pair contains five inputs (i.e., Caffeine concentration (mg/oz), time after consumption (min), age (Years), height (cm) and weight (Kg)) and two outputs (i.e., the systolic and diastolic of the blood pressure of the consumer). The training data set is used to find the initial premise parameters for the membership functions by equally spacing each of the membership functions. A threshold value for error between the actual and desired output is determined. The consequent parameters are computed using the least squares method. Then, an error for each data pairs is found. If this error is larger than the threshold value, the premise parameters are updated using the back propagation neural networks. This process is terminated when the error becomes less than the threshold value. Then, the testing data points are used to compare the model with actual system for validating purposes.

Experimental validation runs were conducted to compare the measured values and the predicted ones. The final fuzzy-based (FIS) model for the systolic blood pressure was formed from 62 total number of parameters, 398 number of training data pairs and 32 number of fuzzy rules. The final fuzzy-based FIS model for the diastolic blood pressure was formed from 190 total number of parameters, 398 number of training data pairs and 162 number of fuzzy rules.

RESULTS AND DISCUSSION

Effect of caffeine consumption on the systolic blood pressure: As can be seen in Fig. 1 that there were elevations of the systolic blood pressure (1-3 mm Hg) with increasing the caffeine concentrations consumption. Also, the main effect can be noticed at 30 and 45 min after the different drinks consumption. These results are very well supported by Lane and Williams (1985) where a limited increasing in the systolic blood pressure was found after consumption caffeinated drinks. However, according to Chvasta and Cooke (1971) it was found that the high intake of caffeinated

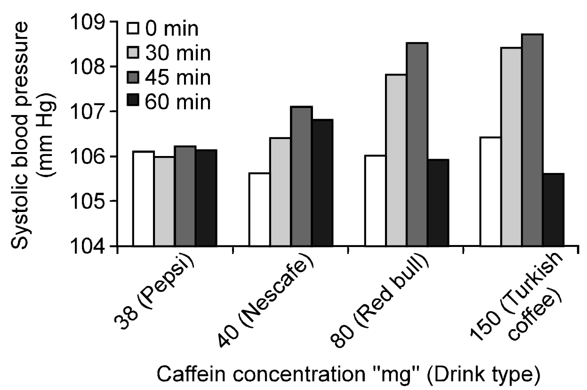

Fig. 1: Effect of different caffeine concentrations on the systolic blood pressure after various times from the drinks consumption

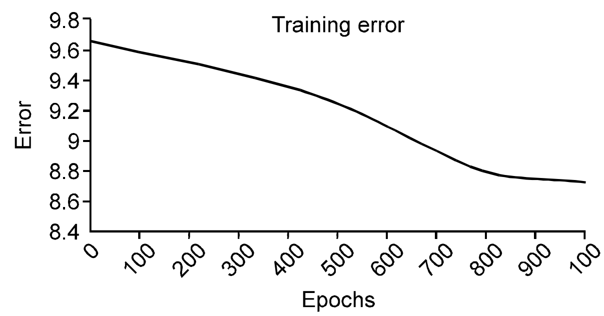

Fig. 2: Final Training curve of Systolic blood pressure model

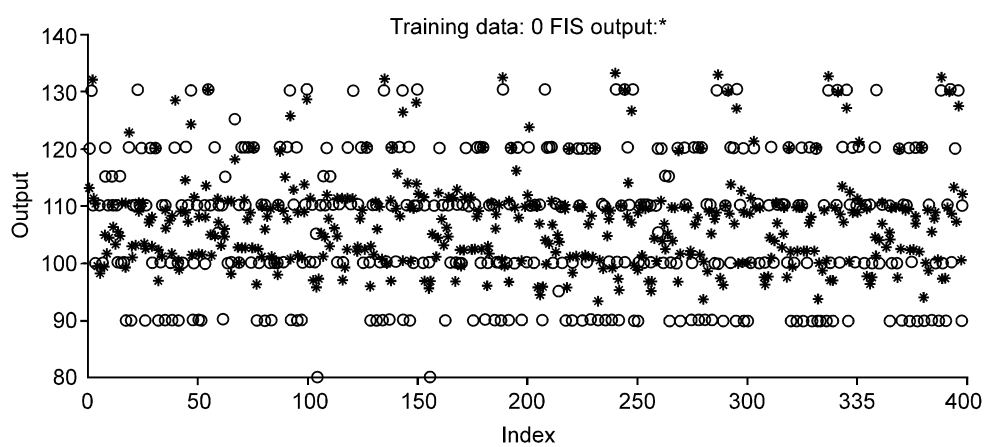

Fig. 3: Training Results (Actual versus modeled output) of the neuro-fuzzy model for the systolic blood pressure

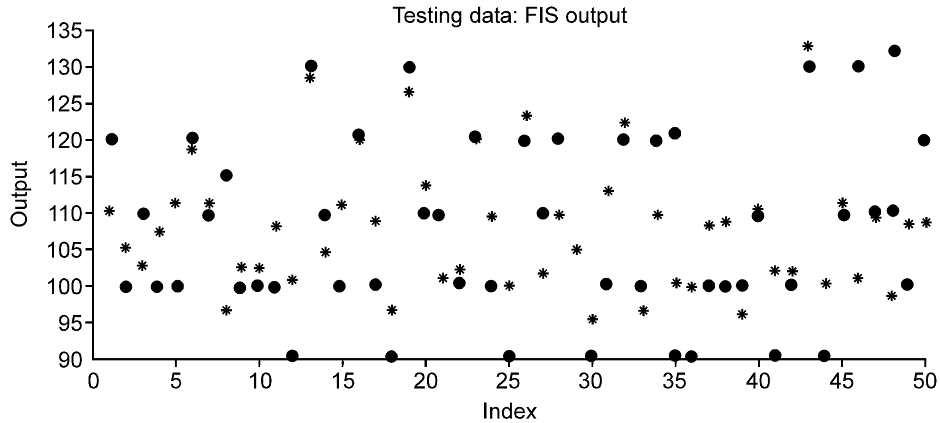

Fig. 4: Testing (validation) results of the systolic blood pressure fuzzy model

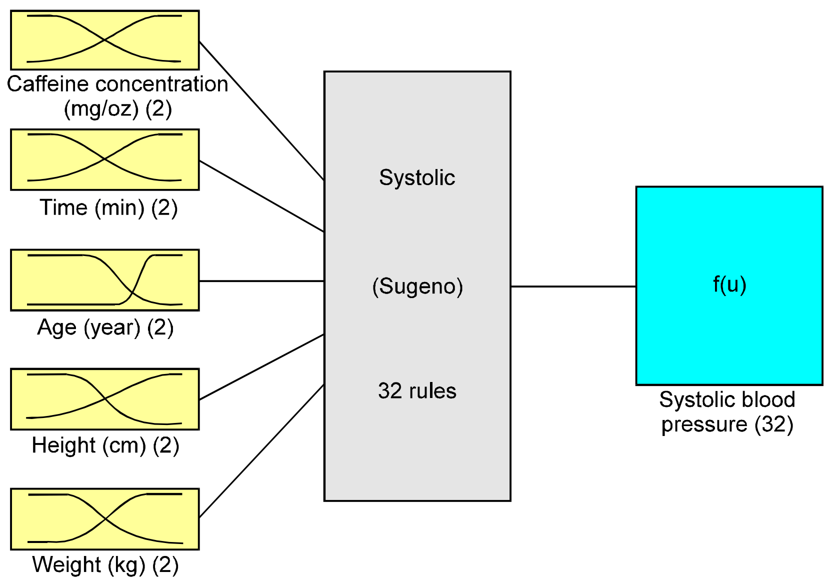

Fig. 5: Final fuzzy-based FIS model for the systolic blood pressure

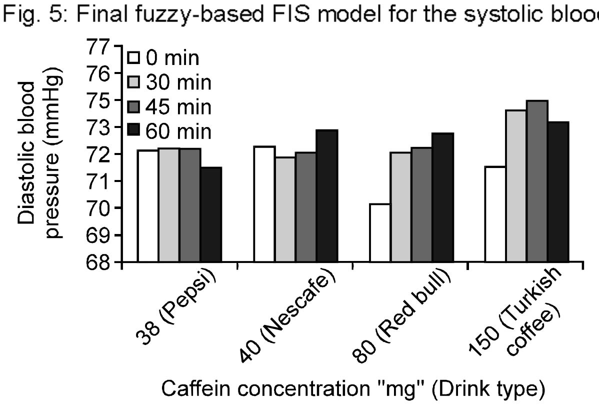

Fig. 6: Effect of different caffeine concentrations on the diastolic blood pressure after various times from the drinks consumption

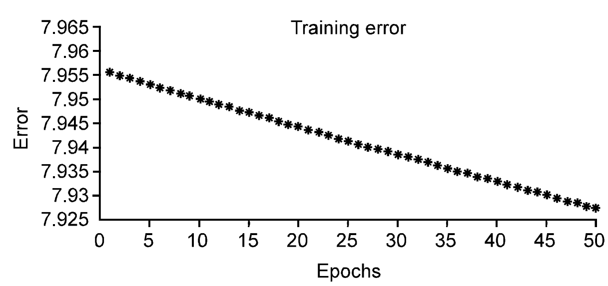

Fig. 7: Final Training curve of diastolic blood pressure model

coffee may influence blood pressure (BP). Also, Nurminen *et al.* (1999) found that single dose of caffeine of 200-250 mg has been shown to increase systolic BP by 3-14 mmHg.

A model for systolic blood pressure: Figure 2 shows the training curve for building a fuzzy model for systolic

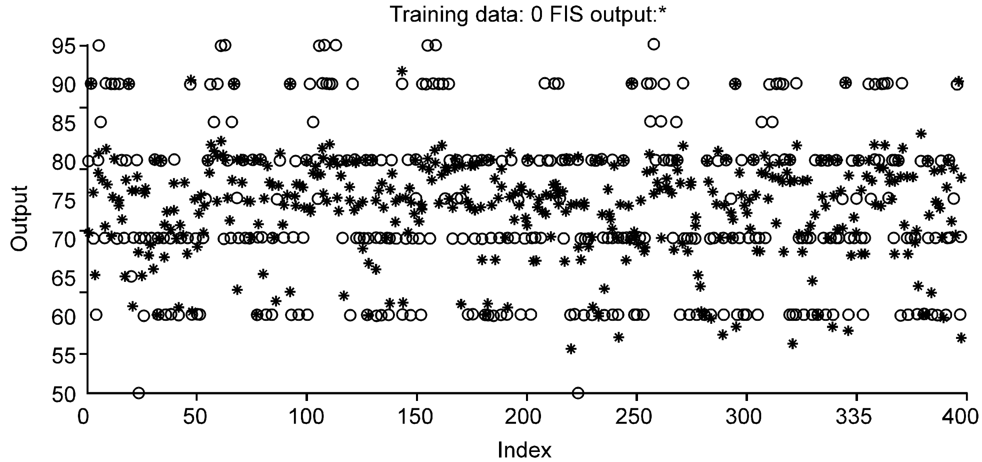

Fig. 8: Training Results (Actual versus modeled output)of the neuro-fuzzy model for the diastolic blood pressure

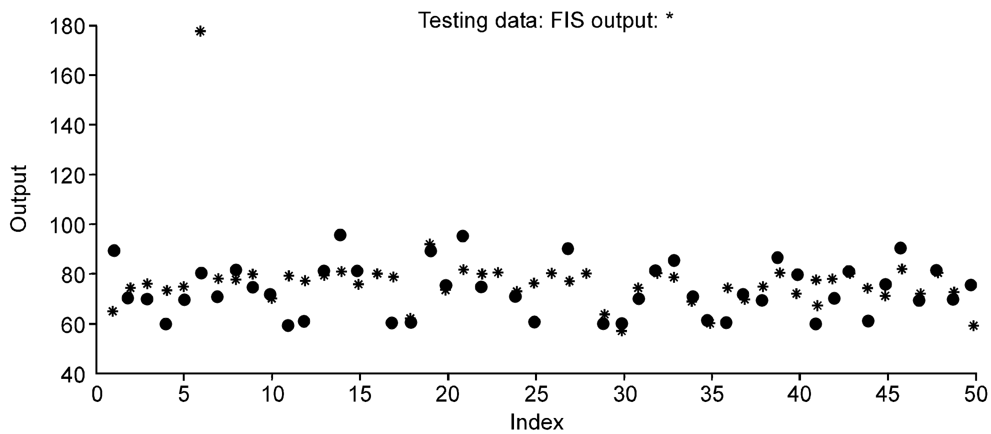

Fig. 9: Testing (validation) results of diastolic blood pressure fuzzy model

blood pressure. 1000 neural nets learning epochs were used to get a low error of training (i.e., RMSE = 8.73 or 10% of the training data range). A comparison between the actual and ANFIS predicted systolic values after training is shown in Fig. 3, which shows that the system is well-trained to model the systolic blood pressure.

Fifty data points, which are different from the training data, were used to validate the system as illustrated in Fig. 4 with average testing (validation) error of 8.9 corresponding to 10% validation error or 90% prediction accuracy. The final fuzzy model of systolic blood pressure is shown in Fig. 5. A two (Bell-shaped) type membership functions for each input resulted in high accurate prediction results. The final fuzzy-based (FIS) model for the systolic blood pressure was formed from 62 total number of parameters, 398 number of training data pairs and 32 number of fuzzy rules.

Effect of caffeine consumption on the diastolic blood pressure: As can be seen in Fig. 6 that there were elevations of the diastolic blood pressure (about 3 mm Hg) with increasing the caffeine concentrations consumption. Also, the maximum effect can be noticed at 30 and 45 min after consumption of a cup of Turkish coffee that contain 150 mg caffeine. Theses results are very well supported by Nurminen *et al.* (1999) where single dose of caffeine of 200-250 mg has been shown to increase diastolic BP by 4-13 mmHg shortly after intake.

A model for diastolic blood pressure: Fifty neural nets epochs were required to train on the data of diastolic blood pressure in order to build a high accurate model. The training root mean square error was found to be 7.93 (i.e., about 9 percent of the training data range), as given in Fig. 7. A comparison between the actual and ANFIS predicted diastolic values after training is shown in Fig. 8. Another fifty points, which are different from the training data, were used to validate the system as illustrated in Fig. 9. The testing (validation) error was 16.6 corresponding to 15% error or 85% prediction accuracy. The final diastolic blood pressure model,

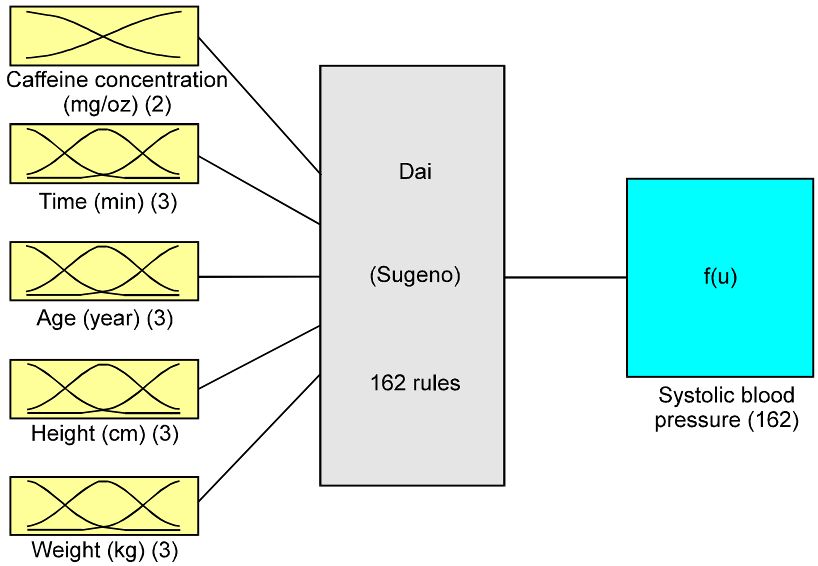

Fig. 10: Final fuzzy-based FIS model for the diastolic blood pressure

generated by ANFIS, is shown in Fig. 10. The Gaussian membership function, with 2 memberships for caffeine concentration input and 3 memberships for each of the other inputs resulted in satisfactorily accurate prediction results. The final fuzzy-based (FIS) model for the diastolic blood pressure was formed from 190 total number of parameters, 398 number of training data pairs and 162 number of fuzzy rules.

Conclusion: In this study, a model for the effect of common caffeine-containing beverages consumption on blood pressure was formulated. In addition, ANFIS fuzzy models for predicting both systolic and diastolic blood pressure, were constructed. The following conclusions can be drawn from the above analysis:

1: There were elevations of the systolic BP (1-3 mm Hg) with increasing the caffeine concentrations consumption. Also, the maximum effect can be noticed at 30 and 45 min after the different drinks consumption
2: The maximum effect of the caffeine consumption on the diastolic BP can be noticed at 30 and 45 min after consumption of a cup of Turkish coffee that contain 150 mg caffeine
3: ANFIS models achieved an average prediction error of the systolic and diastolic blood pressures of about 12%. The present study shows that ANFIS is a technique that can be used efficiently to predict such health and medical measurements and indicators. It is believed that this approach can be applied to predict many other parameters and properties in food and health areas

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