Trajectory Biplot Highlighting Statistically Different Periods for Temporal Sensory Evaluation

Hiroharu Natsume
Tokyo Metropolitan University
Tokyo, Japan

Shogo Okamoto
Tokyo Metropolitan University
Tokyo, Japan

Hikaru Nagano
Kobe University
Kobe, Japan

***Abstract*—The temporal dominance of sensations (TDS) method is used to record time-series sensory changes during daily experiences such as eating food, listening to music, and watching videos. Trajectory biplots are typically used to visualize the data recorded by this method. This trajectory shows how the subjective sensory experience temporarily changes on a principal component plane computed from the records of TDS method. Despite its popularity, there is no method for determining whether two biplots differ statistically. We propose a method for illustrating the periods in which two biplots differ significantly based on their confidence intervals, which are computed using a bootstrap resampling method. This method achieves an effective visualization of the results of the TDS method that can be utilized to evaluate user experiences in consumer electronics.**

***Index Terms*—dynamic experience, sensory evaluation, data visualization**

I. Introduction

The temporal dominance of sensations (TDS) method is used to record multiple sensory changes over time during an experience such as eating food and watching a movie [1]–[3]. Researchers in consumer electronics will benefit from TDS methods because they allow us to investigate how subjective feelings evolve when consumers use products. The experimental results of the TDS method are often visualized using trajectory biplots [1], [4], which present multidimensional time-series data on a two-dimensional principal component plane. However, there is no method for visualizing the periods when the two biplots or experiences from two different products differ statistically. In this study, we propose a method for determining and visualizing such periods using the confidence intervals of trajectories [5]. Thus far, TDS methods have been widely used in food science. We used the TDS data of two ham brands, which were part of the TDS data acquired in a previous study [6].

II. Temporal dominance of sensations method

A. Task of TDS method

In an experiment using the TDS method, an assessor (panel) reports their experience using a computer application over time. The computer screen displays buttons, each of which has a label describing an attribute word such as "sweet" and "sour." When the panel places a food piece in their mouth, they press the start button. The panel then presses a button that corresponds to the most dominant feeling at each moment and selects another button every time the dominant sensation changes. However, multiple buttons cannot be selected simultaneously. As soon as the food vanishes in the mouth, the stop button is pressed, and the task ends.

This study was in part supported by Lotte Foundation (#2023-B-1).

B. TDS curves

The result of the TDS task is multidimensional time-series data. For each attribute word, information on whether it is selected (1) or not (0) at an arbitrary time t is recorded. Here, we formulate the results of TDS following our earlier study [7]. The time series for ith attribute of jth trial ($j = 1, ..., n$) is a function of time t, and is represented by $f_i^{(j)}(t) \in \{0, 1\}$. The number of TDS tasks to be analyzed is n. t is the standardized time ranging from 0 to 1. The moment when the stop button is pressed corresponds to $t = 1$.

The TDS curves are the averages of multiple TDS tasks. The TDS curve of a certain attribute word indicates the temporal evolution of the proportion of dominance, which is the proportion of trials in which an attribute is selected at an arbitrary time. The function $p_i(t)$ corresponding to the TDS curve of ith attribute is

$$p_i(t) = \frac{1}{n} \sum_{j=1}^{n} f_i^{(j)}(t). \quad (1)$$

III. Computation of trajectory plots with confidence intervals

A. Computation of trajectory plot

We followed the method proposed by Lenfant et al. [4] to compute the trajectory plots of the TDS curves. First, a continuous TDS curve $p_i(t)$ was discretized into 1000 intervals in the time domain over $0 \leq t \leq 1$. The discretized curve $P_i[k]$ ($k = 0, 1, ..., 999$) was obtained using the following formula:

$$P_i[k] = 1000 \int_{k/1000}^{(k+1)/1000} p_i(t)\ dt. \quad (2)$$

We performed principal component analysis on $P_i[k]$ with each attribute i ($i = 1, ..., q$) as a variable and obtained $1000 \times s$ principal component scores. Here, s was the number of stimuli evaluated in the TDS tasks. In this study, $s = 2$ because two types of products or experiences were compared. We acquired a trajectory biplot by plotting these scores in time order on a plane defined by the first and second principal

979-8-3503-4017-4/23/$31.00

components. The trajectory exhibited a multidimensional TDS curve on a two-dimensional principal component plane.

B. Computation of confidence intervals

To obtain confidence intervals for the trajectory plots, we resampled the TDS curves using the bootstrap method [3], [5], [8]. In this method, new samples were extracted by sampling the recorded TDS data set with replacement. The size of the resulting sample was the same (n) as the original dataset. The TDS curves and trajectories were computed from a resampled data set.

We repeated the bootstrap method 200 times to generate 200 trajectories for one type of sensory stimulus, i.e., a brand of ham. The standard deviations of the first and second principal component scores of the trajectories were obtained for each ham at each discretized moment. We regarded 1.96 times the standard deviation as the confidence interval. A confidence interval ellipse was then drawn for each moment on a trajectory plot. The confidence intervals for all the discrete moments were overlaid to visualize the uncertainty of the trajectory.

C. Visualization of periods significantly different between two trajectory plots

When a trajectory is inside the confidence interval of another trajectory, the two are assumed not to be significantly different. To visualize these intervals, we drew these parts in a different line style.

IV. Result: Examples of Trajectory Plots with Confidence Intervals

We applied the above method to the TDS task results recorded in a previous study [6]. The trajectories of the two ham products are presented in Fig. 1. The solid curves represent the mean trajectories of the two ham brands. Vectors starting from the origin indicate the direction of individual attributes. The trajectory of Ham A (red) starts from the origin and transitions in directions of *juicy* (dotted red line), *fragile* (orange dotted line), and *umami* (blue dotted line). In contrast, the trajectory of Ham B directs to *sweet* (khaki line) in its early phase. The trajectories of the two hams were close to each other before $t = 0.2$. The blue curve nearly ended at the extension of the dotted orange line, indicating a strongly fragile texture. The red curve ended approximately at the center of the extended orange dotted (*fragile*) and brown (*salty*) lines, indicating that it was fragile and salty at the last moment.

The grey areas were the overlays of the 95% confidence intervals for $t = 0$–1. Light-colored parts of the trajectory showed the intervals in which the trajectory of one product overlapped with another's confidence interval. For example, in the very early phase, these trajectories were not considered significantly different ($t = 0$–0.1). During the periods when the trajectories were drawn in dark red or blue, the sensory experiences of the two brands of hams were significantly different.

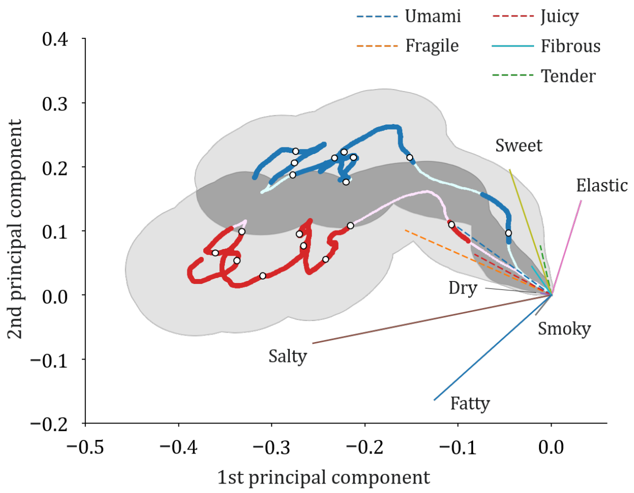

Fig. 1. Trajectory biplots of two brands of hams. The red and blue curves were the trajectories of Hams A and B, respectively. The light grey areas were the overlaid ellipsoids of 95% confidence interval of individual brands of hams. The dark grey areas were the overlaid of the confidence intervals of two brands of hams. At periods during which the curves were dark red or blue, the two trajectories were significantly different from each other. In contrast, during the periods shown by light red or blue trajectories, the two ham products were not significantly different. White circles are plotted every 0.1 normalized time.

V. Conclusion

The trajectory plots are a popular method to visualize the experimental results of the TDS method, which is a time-series sensory analysis method. Thus far, there has been no way to visually indicate whether two trajectory plots drawn on the same trajectory plane differ statistically. We proposed a method to visualize periods in which the trajectories of the two products were significantly different based on the confidence intervals of the trajectory plots. With this visualization method, it is easy to recognize when two stimuli differ significantly in terms of their temporal sensory experiences. In the future, some extensions are needed such that more than two products or trajectories can be visually and statistically compared on the same plane.

References

[1] International Organization for Standarzation, "ISO 13299: Sensory analysis—methodology—general guidance for establishing a sensory profile," standard, Geneva, Switzerland, 2016.

[2] T. Okada, S. Okamoto, and Y. Yamada, "Affective dynamics: Causality modeling of temporally evolving perceptual and affective responses," vol. 13, no. 2, pp. 628–639, 2022.

[3] S. Okamoto, Y. Ehara, T. Okada, and Y. Yamada, "Affective dynamics: Principal motion analysis of temporal dominance of sensations data," *IEEE Transactions on Affective Computing*, vol. 13, no. 2, pp. 871–880, 2020.

[4] F. Lenfant, C. Loret, N. Pineau, C. Hartmann, and N. Martin, "Perception of oral food breakdown. the concept of sensory trajectory," *Appetite*, vol. 52, no. 3, pp. 659–667, 2009.

[5] J. C. Castura, P. Varela, and T. Næs, "Evaluation of complementary numerical and visual approaches for investigating pairwise comparisons after principal component analysis," *Food Quality and Preference*, vol. 107, p. 104843, 2023.

[6] M. Hariu, S. Okamoto, H. Natsume, and T. Doi, “Principal component analysis of time series taste data to classify processed ham,” in *International Symposium on Affective Science and Engineering*, pp. PM–1A–5, 2023.

[7] H. Natsume, S. Okamoto, and H. Nagano, “TDS similarity: Outlier analysis using a similarity index to compare time-series responses of temporal dominance of sensations tasks,” *Foods*, vol. 12, no. 10, p. 2025, 2023.

[8] S. Okamoto, “Structural modeling of temporal dominance responses using covariances of contemporary changes in subjective qualities,” *International Journal of Affective Engineering*, vol. 20, no. 3, pp. 127–130, 2021.