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Comparison of Sensory Acuity of Panels Over the Principles of Signal Detection Theory after Exposing to a Brief Training

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***Abstract*— *Signal detection theory (SDT) is a theoretical framework that can be used to detect the degree of sensory acuity in different sensory panels. This study was conducted to determine the accuracy of a consumer panel (n=75) over SDT principles before and after a basic training. It was performed in two stages to distinguish the sensory acuity of the panel before (consumer state) and after training (sensory-oriented consumer state) in identifying a particular sensory stimulus and also to quantify the perceived perception in terms of rating. The first stage involved yes-no tasks based on SDT that allowed the panelists to respond by discriminating the slightly different two concentrations of sugar solutions. Afterward, responses were categorized over the principles of SDT "hit, miss, false-alarm and correct rejection" and then corresponding probabilities were calculated and compared. The second stage of the study involved rating the sensory perception according to a 5-point hedonic scale. Thereafter, the mean ($\bar{X}$) and standard deviation (σ) for rating were calculated. A chart was developed to determine the number of respondents who indicate their choice over the numbers "1 to 5" of the hedonic scale and the corresponding probability for each number was calculated. Two graphs were drawn one for signal trial and the other for noise trial for two sensory panels. Finally, the rating capacity of respondents in both panels was calculated according to the standard normal distribution formula. Results revealed that the sensory acuity of the panel increases with training because hit (84%) and FA (20%) are significantly different than that of the consumer panel (hit=75% FA=35%) ($p<0.05$). Hence, SDT can be used to gauge the degree of sensory acuity of the respondents in sensory panels.*

***Keywords*— *Consumer panel, Discriminative power, Perceived perception, Sensory acuity, Sensory oriented consumer panel, Signal detection theory (SDT), Training.*

I. Introduction

Signal Detection Theory (SDT) was originated as a probability-based theory in line with the research on radar during world war II in the early 1950s to describe the performance of radars, which detect signals against background noises [1]. Later, it was adopted by cognitive scientists to measure human decision-making in perceptual studies [2]. Although this theory was initially developed in a military context, the scope of SDT has currently extended to a broad spectrum of experimentation in the contemporary world including social and decision-making processes [3] along with sensory studies of auditory and visual detection, cognitive science, diagnostic medicine [4], recognition memory, lie detection, personnel selection, jury decision making, industrial inspection, sensory evaluation and information retrieval [5].

Since human sensory organs are more influenced by variations in the intensity of the stimuli being assessed than most laboratory instruments, they can be used as measurement devices in the sensory analysis [6]. The performance of a sensory panel is a crucial factor for the accuracy of a sensory task. Nevertheless, the performance of a panel depends not only on physiological and psychological factors but also on the level of training and sensory experience of the panelist. Several studies have investigated the effects of training on the panel performance and found that training improves the accuracy of the decision making of the sensory panel while increasing the number of discriminating and consensual attributes [7] as well as elevating attribute ranking agreement [8], reduce variability between assessors [9] and increase the specificity and precision of the vocabulary [10]. STD has been a theoretical framework that can be applied to binary decision-making processes (yes/no), and it can be implemented as a tool in assessing the decision-making process of sensory panelists. Therefore, this study is focused on how SDT can be applied to evaluate the acuity of panelists' decision-making process in order to assess the performance of a consumer panel upon brief training in terms of discriminative capacity as well as perceptual power pertaining to sensory stimulus "sweet taste".

II. Methodology

This study was conducted in two stages on the basis of a yes-no experiment and gauging the perceived perception in terms of rating to identify the discriminative power of the respondents in two types of sensory panels such as consumer panel and sensory-oriented consumer panel according to the framework of SDT. Before beginning the study, a consent form containing information about the study, purpose, and ingredients was provided. The study was conducted in a Food Science laboratory in line with the guidelines of ISO 8589:2007 standards in arranging the test rooms for the sensory evaluation.

A. Participants

Eighty undergraduates of the University of Sri Jayewardenepura, Sri Lanka, were initially selected for this experiment. Thereafter seventy-five undergraduates (75) were selected after screening based on their interest and motivation, personal habits, traits, and health conditions. So also, they were in the age range of 24-26. None of them have previous sensory experiences and are not yet exposed to any practical aspect.

Initially, the selected assessors were assigned as the consumer panel (n=75), and thereafter, they were undergone 30 hours training program to familiarize themselves with different taste attributes, different intensities of taste attributes, hedonic ratings, and sensory lexicons. Further, four 1-h training sessions were conducted to focus on the different intensities of sugar solutions (sucrose) and finally made them familiarize themselves with theory and practical aspects of sensory evaluation. Upon the completion of the training sessions, the participants were categorized as sensory-oriented consumer panels (n=75).

B. Sample preparation

Two sugar (sucrose) solutions with a slightly different concentration (6.50 and 7.00g/L) were prepared, and each solution was divided into two portions to make two sets and each set contained aforesaid two concentrations. Thereafter, these four portions in two sets were coded with four different three-digit numbers such as 303, 403, 503, and 603. While code numbers 303 and 503 were the same level of low concentration, the rest two codes 403 and 603 were also similar high concentration. These solutions were prepared in clean glass containers in fresh and filled in clean glass bottles until serve to the respondents in both panels for the study.

C. Educating the sensory panels

Before beginning the study, the respondents were educated by informing them that they were going to be serving 30ml of sugar solutions in white-color ceramic cups, and thereafter, it should be taken into the mouth and to be kept in the oral cavity for 3-4 seconds while glazing. Thereafter, the mouth should be rinsed with distilled water while swirling. After each test, the mouth should be kept rest or relaxed for preferably 1.0 to 1.5 minutes to diminish the sensory fatigue developed over the sample just before being tested.

D. Yes-no Experiment

This study was based on the yes-no experimental design. One set of sugar solutions which contained slightly low (303), and slightly high (403) sugar concentrations was taken and initially served slightly high concentrated sugar solution (code number 403) and afterward slightly low concentrated sugar solution (code number 303) for the respondents initially who had no training and later they had very brief sensory-related training (Thus, the respondents in both circumstances were considered as two panels) as the signal trial and asked the respondents to indicate their response as "yes" or "no" to the given statement "403 is sweeter than 303" according to their perception. If the panelists were able to respond "yes" by correctly identifying the sugar solution with high concentration, it would be a "hit" and wrongly identified and response is "no", it would be a "miss". The outcome of the study was recorded accordingly as hit and miss.

Afterward, the next set (set 2) of sugar solutions was taken and initially served slightly low concentrated sugar solution (503) and thereafter slightly high concentrated sugar solution (603) as noise trial for the respondents in both panels. Thereafter, the respondents were asked to indicate their response as "yes" or "no" to the given statement "503 is sweeter than 603". If the panelists were able to correctly reject the lower concentration against the other and the response is "no" the decision would be a correct rejection and vis-versa would be a false alarm. The outcome of the trial was recorded accordingly as "correct rejection and false alarm (noise). In this study, each respondent was served two concentrations of sugar solutions in both sets for the signal as well as noise trials. Thereafter, the corresponding probability value for hit and miss as well as correct rejection and the false alarm was calculated for both panels. The same procedure was replicated five times for both consumer and sensory-oriented consumer panels.

E. Gauging the perceived perception of respondents in terms of rating

The objective of the second stage of this study was to measure the perceived perception of the respondents in terms of rating (magnitude of perception) according to a 5-point hedonic scale. Therefore, with serving the first set of solutions where code number 403 was initially served and thereafter 303 for the respondents in both panels in the signal trial, they were asked to rate the magnitude of perception as per the hedonic scale. The same procedure was followed for the rest of the two code numbers 603 and 503 for noise trials where code number 503 was initially served and thereafter code number 303. Finally, the corresponding mean value and standard deviation for the rating of each set (set 1 and set 2) were calculated.

F. Tabulating ratings of the respondents for both sets

A chart was developed to determine the number of respondents who indicate their choice over the numbers "1 to 5" of the hedonic scale for both sets as well as for both panels. Thereafter, the corresponding probability for each number of both sets and both panels was calculated. Two graphs (probability versus hedonic scale numbers), one for hit and miss and the other for correct rejection and noise were drawn for the two panels.

G. Determination of the hedonic variation

To compare the perceived perception (magnitude of perception) of respondents in both sensory panels hedonic scale number pertaining to the probability value of miss in the signal trial as well as a false alarm (noise) in the noise trial was calculated using the following standard normal distribution equation (equation 1).

$$Z = \frac{(X-\bar{X})}{\sigma} \quad (1)$$

Where,
Z = Z score of probability values obtained for miss and false-alarm pertinent to SDT.
$\bar{X}$= Mean rating value for hit and miss trial (signal trial) as well as correct rejection and false alarm trial (noise trial) of both panels.
σ= Standard deviation of rating of hit & miss trial (signal trial) as well as correct rejection & noise trial (noise trial) of both panels.
X= Hedonic scale value, demarcating the probability values of hit and miss as well as right rejection and false alarm of signal and noise trials of SDT respectively.

III. Statistical Analysis

All tests were carried out with five replications and obtained data were analyzed using MINITAB 17 statistical software and MS Excel 2019. Differences were considered statistically significant when $p<0.05$.

IV. Results and Discussion

Two sugar solutions of each set were served to respondents in both sensory panels and asked to identify them over the principles of SDT "hit and miss" in signal trial and "correct rejection and false alarm "in noise trial. In classical yes-no SDT experiments, two possible stimulus events are to be evaluated and there are two possible responses that can be made by the observer. According to the SDT paradigm, a 'Yes' response given to a correct stimulus is called a Hit (H), but a 'Yes' response given to an incorrect stimulus is called a False Alarm (FA) or noise. 'No' response given to a right but the incompatible stimulus is a Correct Rejection (CR); however, 'No' response given to a correct stimulus is a Miss (M) [11]. Based on these, the probability value for the mean response of each category for five (5) replications was calculated and results are given in Table 1.

TABLE 1. Probability values for the mean response of four (4) categories of SDT in identifying sugar solutions by the respondents

Panel	H	M	FA	CR
Consumer panel	0.75 (75%)	0.25 (25%)	0.35 (35%)	0.65 (65%)
Sensory oriented consumer panel	0.84 (84%)	0.16 (16%)	0.20 (20%)	0.80 (80%)

According to SDT, the probability of getting a high percentage of hits and a low percentage of misses can be expected from a sensory-oriented consumer panel in comparison with an untrained panel. Similarly, the same pattern of relationship can be expected from correct rejection and false alarm (noise) too. Referring to table 1, the sensory-oriented consumer panel imparted a high hit rate (84%) and low miss rate (16%) against the consumer panel where hit and miss rates were 75% and 25% respectively for the signal trial. A similar pattern of responses for the noise trial pertaining to the correct rejection and false alarm for the two panels were also observed. In sensory evaluation, as the sensory-oriented consumer panels possessed more discriminative power than that of the consumer panel as a result of the training, respondents in the sensory-oriented consumer panel are capable to secure a high probability value for hit than the untrained consumer panel for the signal trial. As far as the hit rate is concerned, it overlooks the fact that a particular panel might have a higher hit rate just because they are willing to say yes more often, and hence, they are getting more hits at the expense of FA if the panelists undergo sensory test-related training. Thus, the effectiveness of the training can be gauged by both signal and noise trials of SDT. Hence, SDT is an important tool in measuring the sensory acuity of panels. According to previous studies, Macmillan and Creelman (2005) stated that the degree of sensory acuity measure increases when either by increasing the hit rate or decreasing the FA rate. According to this study, the sensory-oriented consumer panel had a lower FA rate, corroborating a high CR rate against the same of the consumer panel in the noise trial. Hence, high hit rate and low FA rate were recorded in the sensory-oriented consumer panel which depicts a higher sensory acuity of the consumer panel over the sugar sensitivity upon training. Further, Wolters and Allchurch (1994) found that undergoing training increased the number of discriminating and consensual attributes in a study of 16 orange juices samples which were assessed by four different panels with 6–8 participants each.

Since the consumer panel has not undergone any study relevant to sensory aspects of foods, a high degree of miss and FA can be expected in comparison with the sensory-oriented consumer panel. However, this relationship can only be observed when the respondents are served with the least different concentrations of two sugar solutions particularly in line with the different threshold levels. According to the studies on SDT by Green and Swets (1966), the decision is affected by several variables, including the consequences for each outcome of judgment, the prior probability of each option, the decision rule that influences the observer, instructions about how to make the observations, the relative frequency of signal and noise trials. Therefore, when a consumer panel is employed for sensory evaluation, a dearth of their knowledge related to those factors can be drastically affected for their decision-making process (for signal and noise tests) in comparison to the sensory-oriented consumer panels, because they have somewhat training towards those variables. Further, even the response of respondents in sensory oriented consumer panel is also not much sharp enough towards the signal and noise trials comparatively trained panels because they are still undergoing training in sensory evaluation.

Gauging the perceived perception of respondents in terms of rating

The second stage of this study was to quantify the perceived perception of the respondents in both consumer and sensory-oriented consumer panels using a 5-point hedonic scale. Hence, respondents were asked to rate the magnitude of perception towards the sugar solutions according to the 5-point hedonic scale in both signal and noise trials. Thereafter, the corresponding mean value and standard deviation (SD) for the rating of signal trial as well as noise trial for both panels in five (5) replications were calculated, and the results are represented in table 2.

TABLE 2. Mean value and SD of ratings of signal and noise trials for consumer panel and sensory oriented consumer panel

	Consumer panel		**Sensory oriented consumer panel**	
	Signal trial	Noise trial	Signal trial	Noise trial
Mean	2.45	2.41	3.03	3.27
SD (σ)	1.21	1.19	1.07	1.04

The data given in table 2 demonstrate that the mean values of ratings of the sensory-oriented consumer panel for signal trial as well as noise trial are significantly higher than that of the consumer panel ($p<0.05$). The reason for this finding is that sensory oriented consumer panel tend to give a relatively high hedonic value for two sugar solutions (low and high) because concentrations between these two sugar solutions are slight and when they are going to rate these two sugar solutions, "the hedonic numbering difference" must be so closed to each other. Further, the degree of discriminative ability of the respondents in the sensory-oriented consumer panel is relatively sharper than that of the consumer panel due to the training. However, in the case of SD, the sensory-oriented consumer panel demonstrates a lower value for both signal (1.07) as well as noise (1.04) trials compared to the consumer panel. A low value of SD indicates that responses of the respondents in the sensory-oriented consumer panel are concise and less deviated against the untrained consumer panel. The reason for this phenomenon is respondents in the sensory-oriented consumer panel have somewhat elevated sensorial experiences and fair judgment as a result of their training and improved brain signal power. Similar results have been demonstrated in the research by Diako, Cooper, and Ross (2016) where the dispersion of ratings around the mean is reduced without significantly affecting the mean value in panelists' bias matrix estimation in a red wine trained panel [12]. Also, Huerta, Jerez, Moron, Rincon, and Caro (1996) found, the training causes to reduce variability between assessors in a study of 37 beefsteaks; where five attributes were assessed using an 8-point descriptive scale by the same panel of seven assessors before and after 40 h training.

Tabulating rating of the respondents to determine hedonic variation and perceived perception

To determine hedonic variation, a chart was developed to indicate the number of respondent/s and their choice over the numerical number 1 to 5 of the hedonic scale as well as to indicate the corresponding probability value for each number. The outcomes of the finding are shown in tables 3 and 4.

TABLE 3. Probability in assigning hedonic scale ratings by the consumer panel

	Scale (signal trial in consumer panel)						Scale (noise trial in consumer panel)				
	1	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**
Hit (n=75)	19	12	20	17	7	**CR (n=75)**	24	10	20	14	7
Miss (n=75)	21	32	13	7	2	**FA (n=75)**	19	31	17	6	2
Total (n=75)	40	44	33	24	9	**Total (n=75)**	43	41	37	20	9
Probability %	26.67	29.33	22.00	16.00	6.00	**Probability %**	28.67	27.33	24.67	13.33	6.00

TABLE 4. Probability in assigning hedonic scale ratings by the sensory-oriented consumer panel

	Scale (signal trial in sensory-oriented consumer panel)						Scale (noise trial in sensory-oriented consumer panel)				
	1	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**
Hit (n=75)	3	11	26	22	13	**CR (n=75)**	3	6	3	11	2
Miss (n=75)	8	27	24	16	0	**FA (n=75)**	2	8	13	2	0
Total (n=75)	11	38	50	38	13	**Total (n=75)**	5	14	16	13	2
Probability %	7.33	25.33	33.33	25.33	8.67	**Probability %**	3.33	9.33	10.67	8.67	1.33

TABLE 5. Hedonic scale numbers (X) pertaining to the probability values of miss and the false alarm

	Miss		**False alarm**	
Panel	Calculated X	Round off to the hedonic number	Calculated X	Round off to the hedonic number
Consumer panel	3.27	3	2.87	3
Sensory oriented consumer panel	4.09	4	4.15	4

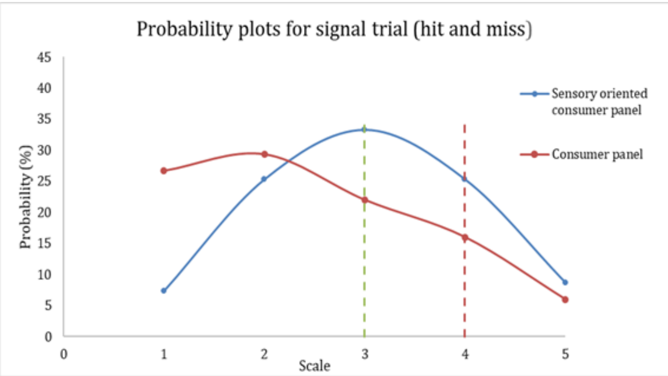

Fig. 1. Probability distribution plot for signal trial of both panels

The corresponding probability values in tables 3 and 4 pertaining to the signal trial and noise trial of consumer panel and sensory oriented consumer panel were used to plot two graphs "probability value of hit and miss versus the hedonic value for both panels in signal trial" as well as "probability value of correct rejection and false alarm versus the hedonic value for both panels in noise trial". Results are illustrated in figures 1 and 2. Thereafter, hedonic scale numbers (X) pertaining to the probability values of miss and the false alarm given in table 1 of SDT relevant to both consumer panel and sensory oriented consumer panel in the signal trial as well as noise trial were calculated using the standard normal distribution formula and the results are shown in Table 5. Based on the calculated values of "X" it was round off to fall in line with the hedonic number.

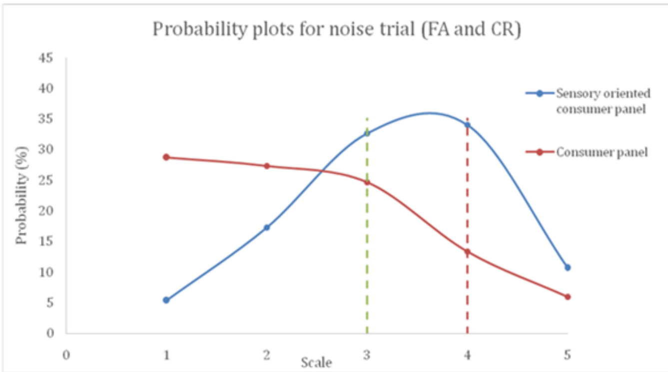

Fig. 2. Probability distribution plot for noise trial of both panels

Referring to the results of table 5, the hedonic scale value (X) demarcating the probability values of hit and miss (Table 1) of the signal trial of SDT for the sensory oriented consumer panel and consumer panel were 4 and 3 respectively. So also, hedonic values for the correct-rejection and false-alarm of the noise trial for the same order of the two panels were 4 and 3. Since the demarcating points between hit and miss of the sensory oriented consumer panel and consumer panel are beginning from 4 and 3 respectively on the hedonic scale, the hit section of the signal trial of the sensory oriented consumer panel is in the range of four (4) to five (5) whereas, it is for the consumer panel from three (3) to five (5). Thus, the sensory-oriented consumer panel has two optional hedonic numbers in the sphere of the hit which is 4 and 5 whereas it is for the consumer panel 3, 4, and 5. Hence with the training, the hedonic variation of the sensory-oriented consumer panel is narrowed down comparatively consumer panel. A similar pattern of relationship has been observed for the false alarm of noise trial too. In the case of false alarm, it is beginning from 4 and 3 of the hedonic scale for the sensory-oriented consumer panel and consumer panel respectively and hedonic variation for the sensory-oriented consumer panel lies in between 4 and 5 whereas it is for the consumer panel in between 3 and 5. Hence, the hedonic scale-space relevant to the signal trial and noise trial of the sensory-oriented consumer panel is narrowed down comparatively consumer panel. However, this relationship can only be observed when the respondents are serving with a least different concentrations of two sugar solutions preferably in line with the different threshold levels. Therefore, according to the outcome of this study, the perceptual power in terms of discriminative talent, as well as sensory acuity (pertaining to the sensory stimulus "sugar taste"), is improving with the training, because the sensory-oriented consumer panel demonstrated this capability clearly against the consumer panel. The apparent reason for this conclusion is that these two sensory panels were served least different two sugar solutions and their perceived numerical values for rating towards the two sugar solutions must be so closed to each other and this type of talent apparently can be expected from a sensory-oriented consumer panel rather than from an untrained consumer panel. Finally, we can conclude that hedonic uncertainty or hedonic indifference over the rating of the sensory stimulus "sugar taste" is narrowed down with the training of the respondents or subjects.

Psychological variability in the conditioning of the subjects can account for controversial results in gustatory signal detection levels in each panel. Sensory knowledge and experience of the panelist are also thought to be affected in deciding the detection of similar stimuli. Physiological factors, neural factors, sensory experience, and familiarity also contribute to the variability of sensory abilities. Therefore, the individual differences in the perception of taste and discrimination between similar confusable stimuli could be observed in sensory panels. As Meilgaard, Civille, and Carr (2013) stated, order of presentation also affects the decision-making process where the panelists use all available clues and depend on the available pattern to make the responses in sensory tasks [13] and thus a variation in responses between two trials could be observed in both panels. According to the previous studies it is assumed and accepted that consumer panels are less sensitive or less discriminative than a panel consisting of appropriately trained subjects where trained panelists are more familiar with the experimental procedures, which in turn allows them to discriminate better among the stimuli under study [14]. Furthermore, Chollet, Valentin, and Abdi (2005) concluded in their research that experts or trained assessors, as well as consumers, discriminate chemo-sensorial stimuli above what would be expected by chance alone, but experts and trained assessors tend to outperform against untrained panels. Experts and trained assessors also tend to be better at matching stimuli to their descriptions than untrained panels who are often at chance level [15].

According to this study, the consumer panel usually lacks the experience, vocabulary, and concept alignment necessary to generate quality descriptive data while the sensory-oriented consumer panel is capable of understanding the sensory vocabulary and has conceptual knowledge up to some extent. Therefore, throughout this study, the sensory-oriented consumer panel indicates higher performance along with a higher discriminative power than that of the consumer panel. Combining the framework of SDT can identify the panelists who are underperforming during sensory tasks and providing the proper continuous training will provide a proper knowledge and understanding of the sensory lexicons ultimately increasing the cognitive power and thus the discrimination ability of the respondents.

V. Conclusions

The main objectives of this study were to determine the effect of training on a consumer panel based on the probabilities of correctly identifying a particular sensory stimulus by one panel over the other and to quantify perceived perception in terms of rating. The results of this study revealed that the sensory-oriented consumer panel has a higher hit and CR rate as well as lower miss and FA rate compared to the consumer panel indicating that the sensory acuity of the sensory-oriented consumer panel is higher than that of the consumer panel. Moreover, results demonstrated that the magnitude of perception of the sensory-oriented consumer panel is higher than the consumer panel and the ability in assigning numerical numbers in ratings more precisely with a least difference. Further, hedonic variation and hedonic uncertainty of the sensory-oriented consumer panel are comparatively lower than that of the consumer panel. Thus, results revealed that the acuity of a consumer panel increases upon the training. However, this sentiment is only valid for the least difference sugar solutions are served for the sensory-oriented consumer panel and consumer panel.

This study further demonstrates the potential use of signal detection theory in assessing the sensory acuity of panels, identifying the training needs of the panelists as well as improving the effectiveness of sensory testing in an industrial context through improving the quality of the decision-making process based on the sensory results and developing a reliable database. However, further studies can be conducted to determine the acuity of trained, semi-trained, and untrained panels over SDT based on the other sensory attributes such as texture and aroma, overall acceptability, etc.

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