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Resolvable Multi-Session Sensory Designs Balanced for Carryover Effects

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SUMMARY

Sensory trials play a vital role in food and nutrition experiments in establishing certain sensory facts about agricultural/animal produce. To draw definite conclusion from the study, it is important to eliminate or minimize all sources of error and control all factors that may influence the inference. Hence, in addition to the potential sources associated with the preparation of the test products, variability due to measurement or assessment process, order effects, carryover effects and assessor fatigue are to be considered. An experimental design for sensory evaluation should be capable of accommodating all these variations. However, when there are a large number of products two operational constraints, *viz*. assessor constraint and preparation constraint, may limit the choice of experimental designs. Assessor constraint sets a maximum number of products that an assessor can evaluate within a session before onset of sensory fatigue and preparation constraint limits the number of products that can be prepared for a given session without loss of experimental control. Therefore, many times it may become necessary to split sensory evaluation into sessions. Here, a general method is developed based on initial sequences to construct designs for multi-session sensory trials balanced for carry over effects. In the proposed designs, all panelists will have to evaluate only a subset of samples in each session and they will not have to taste the same product more than once during different sessions. A possible way of analysis of data generated from such trials is also discussed.

Keywords: Carry over effects, Initial sequence, Multi-session trials, Sensory trials, Variance balance, Williams Latin square.

1. INTRODUCTION

Sensory trials form an important part of food and nutrition experiments involving agricultural/animal produce. In addition to the potential sources associated with the preparation of the products, there is variability due to measurement or assessment process, order effects, carryover effects and assessor fatigue. An experimental design for sensory evaluation should be capable of accommodating all these variations. There should be balancing in the order of presentation of the products to the assessors, but the sequences may be randomly assigned to assessors. The area of designs involving sensory trials is not well developed in literature.

Amerine *et al*. (1965) discussed some basic principles to be followed and analytical procedures for data obtained from sensory trials. Lawless (1984) described two groups of wine consumers where one group was experienced and the other group had no experience and they attempted to match the flavour characteristics of six unlabeled white wines in subsequent tastings. Jones and Wang (2000) described methods of analyzing repeated measures in sensory studies. Husson and Pages (2003) compared the sensory profiles of six dark chocolates done by two types of juries: trained jury and an untrained jury. Analysis of variance showed that the two types of juries gave similar sensory profiles and that the few differences were mainly due to different ways of using the scale. Naes *et al*. (2010) described the most basic statistical methods for analysis of data from trained sensory panels and consumer panels with a focus on applications of the methods. Application of designs like factorial, fractional factorial, split-plot designs, nested designs, randomized complete block designs and incomplete block designs were discussed. In a study by Martinez *et al.* (2014) to evaluate juice

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quality potentials during post-harvest ripening, four apple cultivars were sampled and juiced after 5 and 10 days of post-harvest storage at room temperature (20°C).

Since the evaluations by assessors are made sequentially, there is a fair chance that observation made by an assessor in a particular serving is influenced by the lingering taste of the products that are tasted by the assessor in the previous servings. There is a need to consider these carry over effects while designing such trials. A good review of different classes of designs balanced for carry over effects can be seen in Patterson and Lucas (1962), Afsarinejad (1990) and Hinkelmann and Kempthorne (2005).

Peryam and Pilgrim (1957) reported a significant first position effect for difficult products and suggested that the usage of a design based on a complete set of mutually orthogonal Latin squares (MOLS). Macfie *et al.* (1989) addressed the problem of balancing the effect of order of presentation and the residual effect of a preceding sample over a series of presentations of the same set of samples in a sensory trial using Williams (1949) square designs. Schlich (1993) illustrated the design and analysis of sensory trials taking into account the effects of serving order and previously assessed treatment. Mead and Gay (1995) examined the design of sensory trials in the context of using information from previous trials to improve the information from each new trial.

Wakeling and Macfie (1995) discussed the problem of balancing out carry over effects of preceding samples in consumer trials when each consumer only receives k out of possible t products. For large trials, an 'all possible combinations approach' gave balance for all higher order effects. Kunert (1998) emphasized the importance to use a design which is balanced for carry over effects and not to randomize the order in which the products are tasted. In most sensory studies the products are evaluated one after another and there is concern that the perception of panelists might be influenced by carry over effects. Optimal crossover designs considering a model wherein carry over effects are proportional to the direct effects of treatments were investigated by Kempton *et al.* (2001). A computer search was used to identify optimal designs for the estimation of direct effects. Algorithms were developed by Perinel and Pages (2004) for situation in which the number of subjects is not precisely known before the evaluation. Nonyane and Theobald (2007) described the importance of using treatment sequences which were balanced for first order carry over effects when investigating the phenomenon experimentally with several types or levels of stimulus. Such sequences were suggested by Finney and Outhwaite (1956).

When a large number of products are to be compared, mainly two operational constraints exist. On one hand, the panelist constraint sets a maximum number of products that can be assessed by a panelist in a session, before getting fatigue. *i.e.*, after tasting many samples judges can no longer distinguish between good or bad. It is generally agreed that judges can taste 6-8 products before their discrimination declines badly. On the other hand, the preparation constraint restricts the number of products that can be prepared in a session of cooking. It is usually the panelist constraint which is the more limiting. Therefore, it is many times necessary to split sensory evaluations into sessions. Further, most of the sensory trials are designed using incomplete blocks, in which all panelists evaluate a subset of samples in each session. The number of samples evaluated in a session is mostly determined by the panelist constraint. If resolvable or near resolvable designs are used for the trial, the same judge will not have to taste the same product twice during two different sessions. Hence, resolvable/ near resolvable multi-session sensory designs balanced for carry over effects within sessions, in which a subset of products is assessed in each session, are advisable.

2. MATERIALS AND METHODS

The following additive linear fixed effects model is considered in this study on multi-session sensory trials

$$y_{j(i)klm} = \mu + \eta_i + \pi_{j(i)} + \psi_k + \tau_m + \rho_l + \varepsilon_{j(i)klm} \quad (1)$$

$i = 1, 2, \ldots, s;\; j = 1, 2, \ldots, p;\; m, l = 1, 2, \ldots, v;\; k = 1, 2, \ldots, n$

where μ is the general mean, η_i is the effect of i^{th} session, $\pi_{j(i)}$ is the effect of j^{th} period nested within the i^{th} session, ψ_k is the effect of k^{th} panelist, τ_m is the direct effect of m^{th} food product and ρ_l is the first order carry over effect of l^{th} food product given in the $(j\text{-}1)^{th}$ period in session i to the k^{th} panelist. $\varepsilon_{j(i)klm}$ is random error ~ $N(0,\sigma^2)$. Here, it is assumed that first order carry over effects persist within the sessions. Therefore, if no pre-period is considered before each session ρ_l=0, when j=1.

A method of construction of designs for multi-session sensory trials balanced for carry over effects, based on initial sequences developed from primitive elements of prime numbers, has been described here. The method gives rise to three series of designs, which has been illustrated through appropriate examples. In all the classes, contrasts pertaining to various products are estimated with a constant variance indicating that these designs are variance balanced.

A SAS program has been written in PROC IML to calculate average variance of estimates of contrasts pertaining to direct effects $\overline{V}(\widehat{\tau_i - \tau_j})\sigma^{-2}$ as well as carry over effects $\overline{V}(\widehat{\rho_i - \rho_j})\sigma^{-2}$ of different products for all the designs belonging to the proposed classes. The canonical efficiency factor of the proposed designs in terms of direct effects of products relative to an orthogonal design with the same number of products has been computed by working out the harmonic mean of (1/r) times the non-zero eigen values of the information matrix (Dey 2008) where, r represents the number of replications of direct effects in the proposed design.

3. METHODS OF CONSTRUCTION OF DESIGNS

Method for constructing three series of designs for multi-session sensory trials for number of products (v) is prime or prime power, which takes the form $4t + 1$, $6t + 1$ or $4t + 3$, is developed by defining suitable initial blocks obtained using primitive elements of Gallois Field (G.F.) and then developing them mod (v). Adding pre-periods in each session three classes of designs for multi-sessions trials balanced for carry over effects are obtained.

Case I. $v = 4t + 1$

Let x be the primitive element of $v = 4t + 1$. Obtain t initial columns as follows:

$$\begin{array}{c|c|c|c} x^0 & x^1 & \ldots & x^{(t-1)} \\ x^t & x^{(t+1)} & \ldots & x^{(2t-1)} \\ x^{2t} & x^{(2t+1)} & \ldots & x^{(3t-1)} \\ x^{3t} & x^{(3t+1)} & \ldots & x^{(4t-1)} \end{array}$$

Place these columns one below the other and develop them horizontally by adding one to each preceding column mod (v). There are t initial columns that lead to t sessions. Treating rows as periods and columns as panelists and adding one pre-period (consisting of products from the last period of each session) to each session, a class of designs having parameters $v = 4t + 1$, $s = t$, $p = v - 1$, $n = v$ can be obtained.

The general form of information matrix for this class of designs is obtained as

$$\mathbf{C} = \frac{v(v-3)}{(v-2)}\left(\mathbf{I}_v - \frac{\mathbf{J}_v}{v}\right)$$

Example 3.1. Let $t = 3$ which gives rise to $v = 13$. A design for multi-session sensory trials can be obtained in three sessions, four periods per session and 13 panelists, as follows.

		Periods	Panelists												
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Sessions	I	0	5	6	7	8	9	10	11	12	13	1	2	3	4
		i	1	2	3	4	5	6	7	8	9	10	11	12	13
		ii	8	9	10	11	12	13	1	2	3	4	5	6	7
		iii	12	13	1	2	3	4	5	6	7	8	9	10	11
		iv	5	6	7	8	9	10	11	12	13	1	2	3	4
	II	0	10	11	12	13	1	2	3	4	5	6	7	8	9
		v	2	3	4	5	6	7	8	9	10	11	12	13	1
		vi	3	4	5	6	7	8	9	10	11	12	13	1	2
		vii	11	12	13	1	2	3	4	5	6	7	8	9	10
		viii	10	11	12	13	1	2	3	4	5	6	7	8	9
	III	0	7	8	9	10	11	12	13	1	2	3	4	5	6
		ix	4	5	6	7	8	9	10	11	12	13	1	2	3
		x	6	7	8	9	10	11	12	13	1	2	3	4	5
		xi	9	10	11	12	13	1	2	3	4	5	6	7	8
		xii	7	8	9	10	11	12	13	1	2	3	4	5	6

C-matrix for this design is = 11.818 ($\mathbf{I}_{13} - 0.076\mathbf{J}_{13}$).

Remark: When $t = 1$, design reduces to one for a single session sensory trial involving v =5 products in four periods and 5 panelists.

Case II. $v = 6t + 1$

Obtain t initial columns, using x as the primitive element of $v = 6t + 1$, as follows:

$$
\begin{array}{c|c|c|c}
x^0 & x^1 & \ldots & x^{(t-1)} \\
x^t & x^{(t+1)} & \ldots & x^{(2t-1)} \\
x^{2t} & x^{(2t+1)} & \ldots & x^{(3t-1)} \\
x^{3t} & x^{(3t+1)} & & x^{(4t-1)} \\
x^{4t} & x^{(4t+1)} & \ldots & x^{(5t-1)} \\
x^{5t} & x^{(5t+1)} & \ldots & x^{(6t-1)}
\end{array}
$$

Juxtapose the initial columns vertically one below the other. Develop these columns horizontally by adding one to each preceding column mod (v). There are t initial columns and hence, t sessions. Treating rows as periods and columns as panelists and adding one pre-period (consisting of products from the last period of each session) to each session, a class of designs can be obtained with parameters $v = 6t + 1$, $s = t$, $p = v - 1$, $n = v$.

The general information matrix for this class of designs is obtained as

$$\mathbf{C} = \frac{v\,(v-3)}{(v-2)}\left(\mathbf{I}_v - \frac{\mathbf{J}_v}{v}\right)$$

Example 3.2. Let $t = 2$ which gives rise to $v = 13$. A design for multi-session sensory trials can be obtained in two sessions, six periods per session and 13 panelists, as in Table 1.

The **C** matrix for the estimation of product effects is

$$\mathbf{C} = 11.818\ (\mathbf{I}_{13} - 0.076\mathbf{J}_{13})$$

Remark: When $t = 1$, design reduces to one for a single session sensory trial involving $v = 7$ products in six periods and 7 panelists.

Case III. $v = 4t + 3$

Using even and odd powers of x, the primitive element of v, obtain two initial columns as

$$
\begin{array}{c|c|}
x^0 & x^1 \\
x^2 & x^3 \\
x^4 & x^5 \\
x^6 & x^7 \\
x^8 & x^9 \\
. & . \\
. & . \\
. & . \\
x^{4t} & x^{(4t+1)}
\end{array}
$$

Place these two columns one below the other and develop them horizontally by adding 1 to each preceding column mod (v). There are two sessions corresponding to two initial columns. Treating rows

Table 1

		Periods	Panelists												
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
		0	10	11	12	13	1	2	3	4	5	6	7	8	9
		i	1	2	3	4	5	6	7	8	9	10	11	12	13
		ii	4	5	6	7	8	9	10	11	12	13	1	2	3
	I	iii	3	4	5	6	7	8	9	10	11	12	13	1	2
		iv	12	13	1	2	3	4	5	6	7	8	9	10	11
		v	9	10	11	12	13	1	2	3	4	5	6	7	8
Sessions		vi	10	11	12	13	1	2	3	4	5	6	7	8	9
		0	7	8	9	10	11	12	13	1	2	3	4	5	6
		vii	2	3	4	5	6	7	8	9	10	11	12	13	1
		viii	8	9	10	11	12	13	1	2	3	4	5	6	7
	II	ix	6	7	8	9	10	11	12	13	1	2	3	4	5
		x	11	12	13	1	2	3	4	5	6	7	8	9	10
		xi	5	6	7	8	9	10	11	12	13	1	2	3	4
		xii	7	8	9	10	11	12	13	1	2	3	4	5	6

as periods and columns as panelists and adding one pre-period (consisting of products from the last period of each session) to each session, a class of designs having parameters $v = 4t + 3$, $s = 2$, $p = v - 1$, $n = v$ can be obtained. The general information matrix for this series of designs is

$$\mathbf{C} = \frac{v\,(v-3)(v+1)}{(v^2 - v - 2)}\,(\mathbf{I}_v - \frac{\mathbf{J}_v}{v})$$

Example 3.3. Let $t = 1$ yielding $v = 7$. A design for multi-session sensory trials can be obtained in two sessions, three periods per session and seven panelists, as follows

Sessions		Periods	Panelists						
			I	II	III	IV	V	VI	VII
	I	0	4	5	6	7	1	2	3
		i	1	2	3	4	5	6	7
		ii	2	3	4	5	6	7	1
		iii	4	5	6	7	1	2	3
	II	0	5	6	7	1	2	3	4
		iv	3	4	5	6	7	1	2
		v	6	7	1	2	3	4	5
		vi	5	6	7	1	2	3	4

The information matrix for the estimation of product effects is as follows

$$\mathbf{C} = 9.7778\ (\mathbf{I}_7 - 0.0909\mathbf{J}_7)$$

All the designs obtained are variance balanced. The computed variance estimates of contrasts pertaining to direct effects are same as that of carry over effects, which further indicate that these designs are *totally balanced*.

Table 2 is lists various parameters of designs obtained along with computed variances estimates of contrasts pertaining to direct effects are same as that of carry over effects for $v < 20$.

Table 2. List of designs

S. No.	v	s	p	n	$\overline{V}(\hat{\tau}_i - \hat{\tau}_j)\sigma^{-2}$	$\overline{V}(\hat{\rho}_i - \hat{\rho}_j)\sigma^{-2}$	Efficiency Factor
1	5	1	4	5	0.6	0.6	0.833
2	7	2	6	7	0.357	0.357	0.933
3	7	1	6	7	0.357	0.357	0.933
4	9	2	8	9	0.259	0.259	0.964
5	11	2	10	11	0.204	0.204	0.977
6	13	2	12	13	0.169	0.169	0.984
7	13	3	12	13	0.169	0.169	0.984
8	17	4	16	17	0.127	0.127	0.992
9	19	2	18	19	0.112	0.112	0.993
10	19	3	18	19	0.112	0.112	0.993

4. OUTLINE OF ANALYSIS

The analysis of data obtained from sensory trials is based on the nature of the responses collected. Response can be either qualitative or quantitative. Analysis based on Model (1) is the best option if the responses are quantitative in nature provided all the assumptions of ANOVA are met. However, taste panel data is normally ordinal in nature and hence one may follow the approach suggested by McCullagh (1980) for ordinal data. The linear logistic model or the proportional odds model is used to model data obtained from sensory evaluation experiment on cooked pork by Avery and Masters (1999). Logistic model makes very limited assumptions on the data provided the responses are ordered. This model, by modifying the functional form to accommodate direct effects, carry over effects, session effects and period effects nested within sessions, is recommended for the analysis of data generated from the designs developed in this paper.

5. CONCLUDING REMARKS

The proposed method yields three classes of designs for prime or prime power number of products v (where v is of the form $4t$+1, $6t$+1 or $4t$+3) balanced for carry over effects within sessions. All the three classes give designs in v panelists but require a pre-period before each session. Observations are not recorded from these pre-periods, however they help to meet the condition of balance in terms of carry over effects of the designs. While the first two series of designs require t sessions, third series always involves only two sessions. All designs are variance balanced and have very good efficiency factor. As v increases, the efficiency also shows an increasing trend. However, for a given (v, p, n) parametric combination, the efficiency factor remains same even if there is a change in number of sessions. Therefore, experimenter can choose the number of sessions according to convenience. All the proposed designs are resolvable in the sense that a particular panelist will not have to taste the same product more than once during different sessions. All the methods together cover a wide range of parametric combinations and hence experimenter can obtain an appropriate design suitable for his/her resources available for the trial.

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