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Power analysis in designing an experiment: The effect of acoustic treatments on mung beans

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Design of experiment
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ABSTRAK

Recently, acoustic treatments have become an attention in agricultural studies. Many researchers found that acoustic treatments can be a supplemental factor in enhancing plant growth. However, the researches on this field have been mostly restricted to find the significant effect of their studies. Although extensive researches have been carried out, few studies do not report the sample size used in their experiment. Hence, this study will emphasise on the application of power analysis in the phase of designing an experiment which focus on the experiment to find the effect of acoustic treatments on mung beans. This paper presents a step-by-step guide to find the minimum number of sample size needed to conduct the experiment and how retrospective power analysis is calculated specifically for the data analysis using multivariate analysis of variance (MANOVA). Based on this study, the minimum total sample size estimated to conduct this experiment is 120 to 216. Upon conducting the experiment, the retrospective power is 97.3% and the effect size is 0.096. The effect size obtained can be a reference parameter for future experiment.

Intorduction

Currently, researchers have shown an increased interest on the effect of acoustic treatments on plant growth. Traditionally, talking to plants has subscribed to the belief that it may affect the growth of plants in both either positive or negative growth and development. Talking positively might enhance the growth of plants while spitting out bad words to the plants may detriment their development. Acoustic treatments are increasingly recognised as the supplemental factor that contribute to the growth of various plants. Many researchers have proven that various plants react to different kind of acoustic treatments in both positive and negative manners [1][2][3][4]. Comparatively, little attention has been given to the statistical experimental design of these studies. Researchers has not treated the design of experiments in much details except for [5]. However, the study does not focus on statistical design of experiment but rather to the engineering part to generate acoustic frequencies. Based on previous studies, few researches have not even reported the total sample size used in their experiment.

Hence, in the present study, power analysis will be considered in the phase of designing an experiment as well as detecting the power of the real study. Power analysis is an analysis method that can be used to determine if the experiment provide enough power to make a reasonable conclusion [6]. Power analysis can also be used to calculate the total sample size required to achieve a specified level of power. In a designed experiment, statistical power is simply the probability of making correct decision. In the other words, it is the probability of correctly rejecting the false null hypothesis (H_0). Considering a study that fail to reject null hypothesis, there exist two possibilities of the insignificant result. A possible explanation for the insignificant result is either because of the conclusion made fail to reject null hypothesis is a correct decision where there is no real effect or the sample size is inadequate to either reject or fail to reject the null hypothesis as shown in Table 1. Table 1 presents statistical decision involved in hypothesis testing.

Table.1 THE STATISTICAL DECISION ON HYPOTHESIS TESTING.

	True H_0	***False*** H_0
Fail to reject H_0	Correct decision: Specificity $(1-\alpha)$	Type II error (β)
Reject H_0	Type I error (α)	Correct decision: Power $(1-\beta)$

Power analysis is important to justify the validity of the study based on estimating sample size and statistical power. A research is considered to be not good enough when it could not detect the real effect due to lack of statistical power. Power analysis can be classified into three types which are priori, retrospective and posteriori power analysis [7]. Priori power analysis estimates the sample size calculation. It is important for researchers in the beginning of designing an experiment to select adequate sample sizes [8]. Inadequate sample sizes may lead to the missing of detecting the real effect. Meanwhile, too large sample size may result in unnecessary wastage of resources. Hence, proper sample size calculation is required before conducting an experiment.

In power analysis, there are several parameters that need to be considered which are effect size, type I error, power of the study and statistical test [9]. Effect size is the measure of how minimum differences between the groups that can be considered significant. Type I error is significance level which usually fixed at while power is as mentioned above, the probability in finding an effect which generally may kept from 80% to 99%. For priori power analysis, it is important to have an idea about the statistical test that are desired to be employed on the data. Different statistical test has different methods of power calculation. Hence, it is important to know what kind of statistical test that is suitable for the data.

Contrary to priori power analysis, posteriori power analysis works such that the sample size being determined first and the amount of power was estimated based on the sample size, effect size and alpha level. Meanwhile, retrospective power analysis is the observed power that was done solely based on the experimental data collected. In this paper, we only consider two types of power analysis which are priori and retrospective which focus on power analysis for multivariate analysis of variance (MANOVA). Firstly, priori power analysis is run to decide the minimum total sample size required in order to obtain result with high power. Secondly, retrospective power is calculated to find the observed power in the real data upon conducting the experiment. This paper will discuss on experiment that consists of one factor with six levels and three continuous response variables.

Method

Steps in Conducting Priori Power Analysis

Figure 1 presents a flowchart which summarise the steps in conducting priori power analysis. In the phase of designing an experiment, researchers must be clear on the main objective to conduct the experiment. Firstly, statistical hypothesis for the experiment should be formulated. Following that, the design of experiment was determined. Then, methods for data analysation should be specified and the assumptions of the statistical methods chosen were identified. There are wide ranges of data analysation methods so the researcher must be aware of the most suitable method that should be applied based on their experimental design. After that, the desired power, significance level and effect size of the experiment must be specified for the calculation of minimum sample size required. G*Power [10] was used to calculate the priori power analysis to generate the minimum sample size estimation.

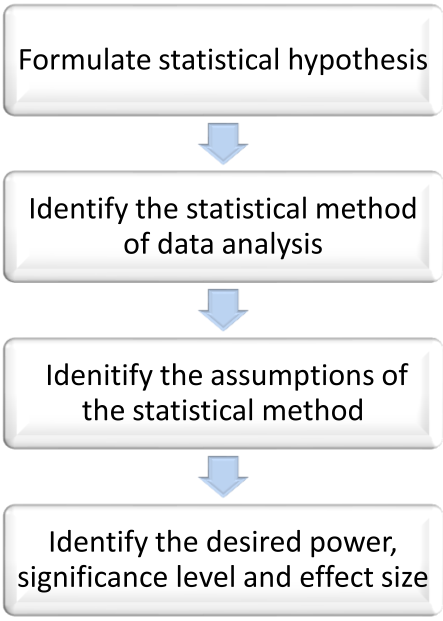

Figure 1. Flowchart of priori power analysis

In conducting an experiment which deal with real data, it is very natural to encounter any attrition. The expected attrition might be due to the ungerminated seeds, unidentified death of plants, plants destroyed by animals and etcetera. Hence, expected attrition should be specified and the total minimum sample size required will be more accurate which consider the expected attrition [11]. The corrected minimum sample size can be calculated such that:

$$N_{corrected} = \frac{N}{1 - \%_{attrition}} \tag{1}$$

where is the total sample size generated from G*Power and is the percentage of attrition estimated based on the experimental design.

Application of Priori Power Analysis in the Experiment

The main objective of this experiment is to find the significant effect of acoustic treatments on the growth of mung beans. Factor considered in this experiment is acoustic treatments with six levels. The acoustic treatments were exposed to mung beans in chambers for three hours every morning. Five various acoustic treatments were exposed to mung beans in five different chambers which were Western classical, nature sound, rock music, soprano and Quranic recitation. The remaining one chamber acts as a control. The experimental data was recorded on day 15 of the growth of mung beans. The response variables measured were length of stem, number of leaves and length of root. The experiment was designed to analyse the data based on MANOVA looking at the effect of acoustic treatments on the growth of mung beans. Hence, the statistical hypothesis of this study was:

$$H_0 : \boldsymbol{\mu}_1 = \boldsymbol{\mu}_2 = \boldsymbol{\mu}_3 = \boldsymbol{\mu}_4 = \boldsymbol{\mu}_5 = \boldsymbol{\mu}_6 \tag{2}$$

which the null hypothesis is the mean vector for every groups are equal and the alternative hypothesis is given by:

$$H_1 = \boldsymbol{\mu}_i \neq \boldsymbol{\mu}_j \tag{3}$$

For $i \neq j$, the mean vector is not equal for at least two different groups.

The experimental design was conducted based on complete randomised design (CRD) and the experimental data will be analysed using MANOVA. Before conducting MANOVA, the data should meet the assumptions of MANOVA which are the observations are independent, the data is normal, the covariance matrices are equal and the response variable are correlated.

Following that, the desired parameters for priori power analysis is specified. In this experiment, we consider the minimum power to be 80% because and the alpha level is set at 0.05. For effect size, usually we can set the effect size based on previous findings and so on. However, no effect size reported in this field. Hence, we set the effect size, f based on Cohen's medium effect [6], [12] which is $f = 0.25$. Thus, the effect size for MANOVA, $f^2(V)$ is set to be $f^2(V) = 0.0625$.

Retrospective Power Analysis based on MANOVA

The experiment was conducted based on the corrected total sample size calculated. Upon conducting the experiment, retrospective power analysis can be conducted based on the responses recorded. The experimental data was checked with the assumption and statistical analysis desired. In this paper, we used exact power calculation which are applied in most software packages. The calculation of power is given as [12]:

$$Power = 1 - \beta \tag{4}$$

where β is the probability fail to reject null hypothesis. The non-centrality parameter, λ can be calculated such that

$$\lambda = df_1 F = \frac{\eta^2_{partial} df_2}{1 - \eta^2_{partial}} \tag{5}$$

where is F is the value from F-test, df_1 is the hypothesis degree of freedom, df_2 is the error degree of freedom and $\eta^2_{partial}$ is the partial eta-squared which represent the effect size for MANOVA. The equation of finding the partial eta-squared is:

$$\eta^2_{partial} = \frac{SS_{effect}}{SS_{effect} + SS_{error}} = \frac{df_1 F}{df_1 F + df_2} \tag{6}$$

where SS_{effect} is the sum of squares of the effect of interest and SS_{error} is the sum of squares for error term associated with the effect of interest. The result of MANOVA and retrospective power analysis were applied using IBM SPSS Statistics Version 25.0.

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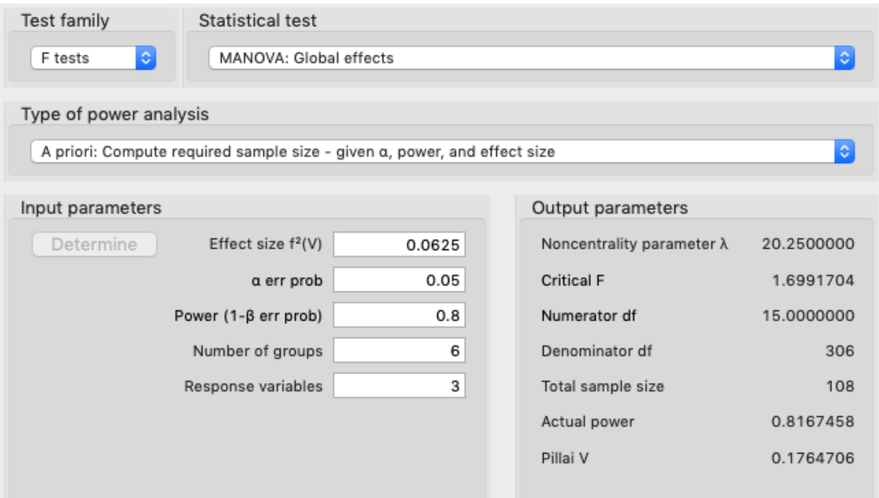
Result and Discussion

Figure 2 shows the output for priori power analysis based on the desired power of 0.8, effect size of 0.0625, alpha level of 0.05 with six groups of acoustic treatments and three response variables. Based on the figure, it is estimated that the minimum total sample size required for mung bean seeds is 108. This means that every group needs 18 seeds to be grown. However, considering expected attrition of 10%, the   is 120 as shown in Table 2. Table 2 displays the corrected total sample size based on expected attrition ranging from 10% to 50% for the specified parameters mentioned above which were calculated using Equation (1). The values of   can also be rounded to the nearest suitable value so that all groups will obtain equal sample sizes. In the case of using some seeds that has low probability of successful growth, we may consider the 50% expected attrition. From the table,   for expected attrition of 50%. This may support any observations missing during the experiment in the case of unsuccessful growth.

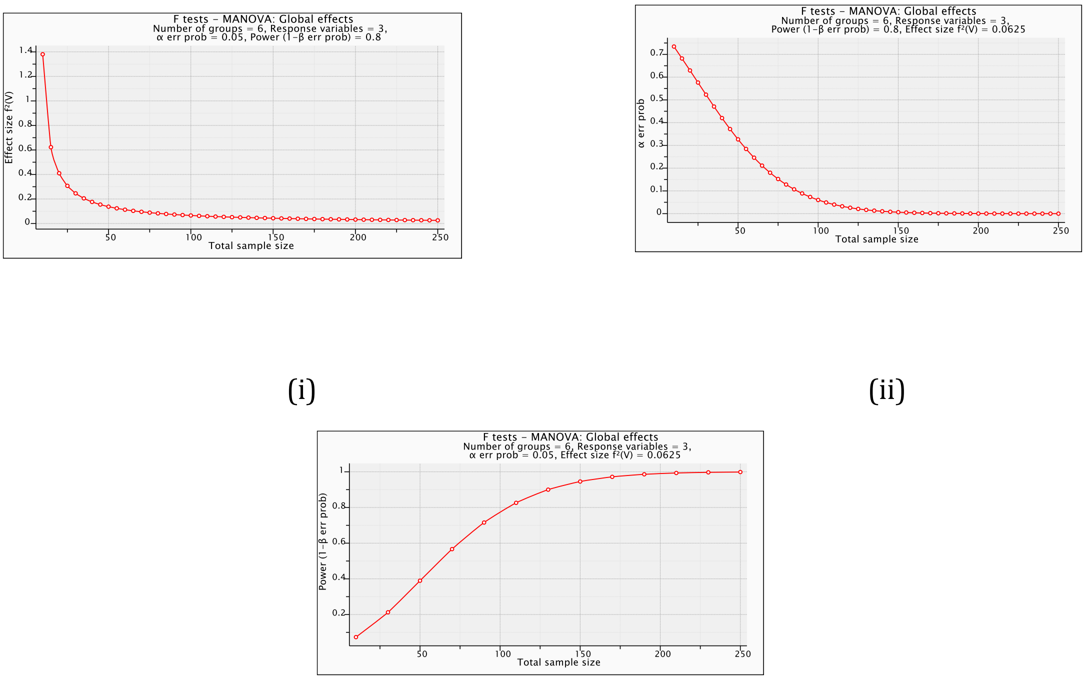


Gambar 1. The output of sample size calculation from G*Power

Table.2 THE CORRECTED TOTAL SAMPLE SIZE BASED ON EXPECTED ATTRITION

Expected attrition (%)	$N_{corrected}$
10	120
20	135
30	154
40	180
50	216

Figure 3 presents the plot of effect size, alpha level and power versus total sample size for sample size ranging from 10 to 250. Based on the figure, we can see that both small effect size and small alpha level require larger total sample size. Meanwhile, to achieve higher power in a study, we need to consider larger total sample size. This means that to detect the real effect, large sample size is needed but how large the sample size needed can be obtained from power analysis. Hence, this could reduce the waste of resources. The series of power analyses yielded the suitable total sample size of 120 to 216 considering the expected attrition.



(i) (ii)

(iii)

Figure 1. Graph plot of (i) effect size versus total sample size (ii) alpha level versus total sample size and (iii) power versus total sample size

The experimental data was analysed using MANOVA and the assumptions were met. This study does not engage with the discussion on MANOVA and the follow up test for this study can be obtained from Abdullah [13]. Table 3 shows the result of MANOVA with retrospective power included with partial eta-squared and non-centrality parameter that can be calculated as in Equation (4-6).

Table.3 MANOVA AND RETROSPECTIVE POWER RESULT

Sources of variation	***Acoustic treatments***			
Test statistics	***Pillai's trace***	***Wilk's lambda***	***Hotelling's trace***	***Roy's largest root***
Value	0.281	0.738	0.330	0.214
F	2.334	2.382	2.414	4.853
df_1	15	15	15	5
df_2	339.000	306.824	329.000	113.000
p-value	0.003	0.003	0.002	0.000
$\eta^2_{partial}$	0.094	0.096	0.099	0.176
λ	35.004	32.727	36.209	24.173
Retrospective power	0.983	0.973	0.986	0.976

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Based on Table 3, we only reported the test statistics of Wilk's lambda. The power of this study is 97.3% which is expected to be high as we have done the priori power analysis from the beginning. Furthermore, we can see that the effect size which were calculated based on is 0.096. This means that there is 9.6% of variance effect of group differences in the MANOVA. This percentage value is sufficient to do post hoc analysis. Although few researchers does not recommend the retrospective power analysis [14] as the observed power is dependent on the observed significance level, the observed effect size is actually beneficial for future research in this field. This is because both statistical significance and effect size are two components that complements each other in order to report findings [15].

Conclusions

From our study, we suggest that researchers need to include the justification of sample size obtained for their experiment. Power analysis is important in the phase of designing an experiment where total sample size can be estimated. Estimation of sample size is the key to perform an effective experiment. It is also beneficial to use retrospective power analysis which the effect size obtained can be a reference for the future experiment. Based on our study, we suggest the sample size of 120 plants which are adequate to detect minimal real effect when applying MANOVA for data analysis with a factor of six levels and three continuous response variables. For an effect size value of 0.096, this can be a reference parameter in the future experiment with similar procedure.

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References

[1] W. Cai, N. T. Dunford, N. Wang, S. Zhu, and H. He, "Audible sound treatment of the microalgae Picochlorum oklahomensis for enhancing biomass productivity," *Bioresour. Technol.*, vol. 202, pp. 226–230, 2016, doi: https://doi.org/10.1016/j.biortech.2015.12.019.

[2] L. Qi, G. Teng, T. Hou, B. Zhu, and X. Liu, "Influence of Sound Wave Stimulation on the Growth of Strawberry in Sunlight Greenhouse," *HAL*, vol. 317, no. 317, pp. 0–7, 2014.

[3] R. Z. Alavijeh, O. Sadeghipour, H. Riahi, and S. V. Dinparvar, "The Effect of Sound and Music on Some Physiological and Biochemical Traits, Leaf Nutrient Concentration and Grain Yield of Cowpea," *IIOAB J.*, vol. 7, no. 2, pp. 447–458, 2016.

[4] B. Ming-e, J. Shi-ren, L. Nan, H. Li-xing, and H. Wen-bin, "Effect of Insect Acoustic and Music Acoustic Frequency on The Growth of 6 Kinds of Vegetables," *Agric. Sci. Technol.*, vol. 11, no. 3, pp. 90–93, 2010.

[5] W. Cai, S. Zhu, W. Ning, H. He, and B. Ying, "Design of an experimental platform to investigate the effects of audible sounds on plant growth," *Int. J. Agric. Biol. Eng.*, vol. 8, no. 5, pp. 162–169, 2015, doi: https://doi.org/10.3965/j.ijabe.20150805.1556.

[6] J. Cohen, *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed. New York, US: Lawrence Erlbaum Associates, 1988.

[7] A. Nair, "Augmentation of Experimental Design Using Statistical Power," Rochester Institute of Technology, 2016.

[8] D. Kelly, "Statistical Power Analysis for Sample Size Estimation & Understanding Risks in Experiments," pp. 822–825, 2015.

[9] G. P. Quinn, M. J. Keough, P. S. Petraitis, G. P. Quinn, and M. J. Keough, *Experimental design and data analysis for biologists*, vol. 277, no. 2. 2002.

ISSN 2774-3241

[10] F. Faul, E. Erdfelder, A.-G. Lang, and A. Buchner, "G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences.," *Behav. Res. Methods*, 2007.

[11] J. Charan and T. Biswas, "How to calculate sample size requirements," *Indian J Psycol Med.*, vol. 34, no. 2, pp. 121–6, 2013, doi: https://doi.org/10.4103/0253-7176.116232.

[12] S. Chartier and J. F. Allaire, "Power Estimation in Multivariate Analysis of Variance," *Tutor. Quant. Methods Psychol.*, vol. 3, no. 2, pp. 70–78, 2007, doi: https://doi.org/10.20982/tqmp.03.2.p070.

[13] N. A. H. Abdullah, A. M. Noor, M. H. F. Rahiman, and K. A. Rani, "Multivariate analysis of variance followed by descriptive discriminant analysis: An analysis of the acoustic treatments effect on mung beans' growth," 2018, p. 020012, doi: 10.1063/1.5054211.

[14] J. M. Hoenig and D. M. Heisey, "The Abuse of Power : The Pervasive Fallacy of Power Calculations for Data Analysis," *Am. Stat.*, vol. 55, no. 1, pp. 1–6, 2001, doi: https://doi.org/10.1198/000313001300339897.

[15] X. Fan and T. R. Konold, "Statistical Significance Versus Effect Size," *Int. Encycl. Educ.*, pp. 444–450, 2010.