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Publications:

lmerTest Package: Tests in Linear Mixed Effects Models
One of the frequent questions by users of the mixed model function lmer of the lme4 package has been: How can I get p values for the F and t tests for objects returned by lmer? The lmerTest package extends the "lmerMod" class of the lme4 package, by overloading the anova and summary functions by providing p values for tests for fixed effects. We have implemented the Satterthwaite's method for approximating degrees of freedom for the t and F tests. We have also implemented the construction of Type I - III ANOVA tables. Furthermore, one may also obtain the summary as well as the anova table using the Kenward-Roger approximation for denominator degrees of freedom (based on the KRmodcomp function from the pbkrtest package). Some other convenient mixed model analysis tools such as a step method, that performs backward elimination of nonsignificant effects - both random and fixed, calculation of population means and multiple comparison tests together with plot facilities are provided by the package as well.

General information
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Authors: Kuznetsova, A. (Intern), Brockhoff, P. B. (Intern), Christensen, R. H. B. (Intern)
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Changes in sensory characteristics and their relation with consumers' liking, wanting and sensory satisfaction: Using dietary fibre and lime flavour in Stevia rebaudiana sweetened fruit beverages

The beverage industry has long revolved around sugar reduction as a response to heightened calorie and health awareness. More recently dietary fibre has also garnered attention to meet the consumer's demands for low calorie and yet more satiating food and beverages. From a health perspective the sweetener Stevia rebaudiana and the fibre β-glucan seem like very good solutions, as stevia is the only natural non-nutritive sweetener and β-glucans have been related to various health benefits besides increasing satiety. However, both also have distinctive perceptual effects on the sensory characteristics of the products they are added to. To gain knowledge on the sensory characteristics of fruit based beverages sweetened with S. rebaudiana and added β-glucans and lime flavour, and how consumers respond to the products, sensory descriptive analysis and a consumer study were conducted. The sensory characteristics of the fruit drinks were affected by stevia and the addition of β-glucans. However, the addition of lime flavour was able to mask the side effect of the aftertaste caused by S. rebaudiana. Further, by adding lime flavour to the fruit beverages, the side effects of increased fibre concentration “Unfresh odour” and “Metallic odour” could also be counteracted to such an extent that the β-glucans containing fruit beverages were evaluated just as favourably in terms of liking, wanting and sensory satisfying as the fruit beverages not containing β-glucans.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Statistics and Data Analysis, Aarhus University
Authors: Mielby, L. H. (Ekstern), Andersen, B. V. (Intern), Jensen, S. (Intern), Kildegaard, H. (Ekstern), Kuznetsova, A. (Intern), Eggers, N. (Ekstern), Brockhoff, P. B. (Intern), Byrne, D. V. (Ekstern)
Delta-tilde interpretation of standard linear mixed model results

We utilize the close link between Cohen's d, the effect size in an ANOVA framework, and the Thurstonian (Signal detection) d-prime to suggest better visualizations and interpretations of standard sensory and consumer data mixed model ANOVA results. The basic and straightforward idea is to interpret effects relative to the residual error and to choose the proper effect size measure. For multi-attribute bar plots of F-statistics this amounts, in balanced settings, to a simple transformation of the bar heights to get them transformed into depicting what can be seen as approximately the average pairwise d-primes between products. For extensions of such multi-attribute bar plots into more complex models, similar transformations are suggested and become more important as the transformation depends on the number of observations within factor levels, and hence makes bar heights better comparable for factors with differences in number of levels. For mixed models, where in general the relevant error terms for the fixed effects are not the pure residual error, it is suggested to base the d-prime-like interpretation on the residual error. The methods are illustrated on a multifactorial sensory profile data set and compared to actual d-prime calculations based on Thurstonian regression modeling through the ordinal package. For more challenging cases we offer a generic “plug-in” implementation of a version of the method as part of the R-package SensMixed. We discuss and clarify the bias mechanisms inherently challenging effect size measure estimates in ANOVA settings.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Statistics and Data Analysis, Universidade Federal de Lavras, Bang & Olufsen A/S
Authors: Brockhoff, P. B. (Intern), Amorim, I. D. S. (Ekstern), Kuznetsova, A. (Intern), Bech, S. (Ekstern), de Lima, R. R. (Ekstern)
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Scopus rating (2012): SJR 0.958 SNIP 1.742 CiteScore 2.6
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Visualizing multifactorial and multi-attribute effect sizes in linear mixed models with a view towards sensometrics

In Brockhoff et al (2016), the close link between Cohen's d, the effect size in an ANOVA framework, and the so-called Thurstonian (Signal detection) d-prime was used to suggest better visualizations and interpretations of standard sensory and consumer data mixed model ANOVA results. The basic and straightforward idea is to interpret effects relative to the residual error and to choose the proper effect size measure. For multi-attribute bar plots of F-statistics this amounts, in balanced settings, to a simple transformation of the bar heights to get them transformed into depicting what can be seen as approximately the average pairwise d-primes between products. For extensions of such multi-attribute bar plots into more complex models, similar transformations are suggested and become more important as the transformation depends on the number of observations within factor levels, and hence makes bar heights better comparable for factors with differences in number of levels. For mixed models, where in general the relevant error terms for the fixed effects are not the pure residual error, it is suggested to base the d-prime-like interpretation on the residual error. The methods are illustrated on a multifactorial sensory profile data set and compared to actual d-prime calculations based on ordinal regression modelling through the ordinal package. A generic "plug-in" implementation of the method is given in the SensMixed package, which again depends on the ImerTest package. We discuss and clarify the bias mechanisms inherently challenging effect size measure estimates in ANOVA settings.
Automated mixed ANOVA modeling of sensory and consumer data

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- **Authors:** Kuznetsova, A. (Intern), Christensen, R. H. B. (Intern), Bavay, C. (Ekstern), Brockhoff, P. B. (Intern)
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- **ISI indexed (2012):** ISI indexed yes
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- **BFI (2011):** BFI-level 1
- **Scopus rating (2011):** SJR 1.051 SNIP 1.367 CiteScore 1.97
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- **Web of Science (2011):** Indexed yes
- **BFI (2010):** BFI-level 1
- **Scopus rating (2010):** SJR 1.014 SNIP 1.818
- **Web of Science (2010):** Indexed yes
- **BFI (2009):** BFI-level 1
- **Scopus rating (2009):** SJR 0.929 SNIP 1.531
- **Web of Science (2009):** Indexed yes
- **BFI (2008):** BFI-level 2
- **Scopus rating (2008):** SJR 0.865 SNIP 1.548
- **Web of Science (2008):** Indexed yes
- **Scopus rating (2007):** SJR 1.024 SNIP 1.893
Linear mixed models in sensometrics

Today's companies and researchers gather large amounts of data of different kind. In consumer studies the objective is the collection of the data to better understand consumer acceptance of products. In such studies a number of persons (generally not trained) are selected in order to score products in terms of preferences. In sensory studies the aim is the collection of the data to better describe products and differences of the products according to a number of sensory attributes. Here trained persons, so-called assessors, score the products in terms of different characteristics such as smell, taste, texture, sound - depending on the aim of a study. It is a common approach in both studies to consider persons coming from a larger population, which, from the statistical perspective, leads to the use of mixed effects models, where consumers/assessors enter as random effects (Lawless and Heymann, 1997).

Mixed effects models have been used extensively in analysis of both consumer and sensory studies. However frequently too simplistic models are considered, important effects are not accounted for and as a consequence important information is not gained or analysis leads to improper conclusions. The focus of this project is to propose a methodology for analyzing more complex models together with tools facilitating the methodology. This was accomplished by contributing to the mixed effects ANOVA modelling in general and specifically applied to sensory and consumer studies through a series of papers and software tools facilitating the developed methodologies. The primary advantage of the ANOVA approach is that it gives confidence intervals and significance tests for the various effects including the background variables used in the model and consequently a fast and reliable assessment and ranking of the importance of different factors.

There exists today very little easily available methodology and software which supports consumer studies with both sensory properties and background information related to health benefits, environment and user-friendliness. In close collaboration with the industrial partners an open-source software tool ConsumerCheck was developed in this project and now is available for everyone. will represent a major step forward when concerns this important problem in modern consumer driven product development. Standard statistical software packages can be used for some of the purposes, but for the specific problems considered here and for the typical users in industry, these programs are far from satisfactory. Therefore, the ConsumerCheck software represents a novel source of information for all quality-oriented industries. The effect is improved procedures for product development and hence improved quality of decision making in Danish as well as international food companies and other companies using the same methods.

The two open-source R packages lmerTest and SensMixed implement and support the methodological developments in the research papers as well as the ANOVA modelling part of the ConsumerCheck software. The SensMixed package is a package for semi-automated analysis of sensory and consumer studies within linear mixed effects framework. The lmerTest package supports tests for linear mixed effects models fitted with the lmer function of the lme4 package (Bates et al., 2013). While SensMixed is closely connected with sensometrics field, the lmerTest package has developed into a generic statistical package.

Reference manuals accompany these R packages.
SensMixed R package: Easy-to-use application with graphical user interface for analyzing sensory and consumer data within a mixed effects model framework

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Authors: Kuznetsova, A. (Intern), Brockhoff, P. B. (Intern), Amorim, I. D. S. (Intern), Mielby, L. (Ekstern), Bech, S. (Ekstern), Ribeiro de Lima, R. (Ekstern)
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Consideration of sample heterogeneity and in-depth analysis of individual differences in sensory analysis
In descriptive sensory analysis, large variations may be observed between scores. Individual differences between assessors have been identified as one cause for these variations. Much work has been done on modeling these differences and accounting for them through analysis of variance (ANOVA). When the products studied are prone to biological heterogeneity (e.g., fruits, vegetables, cheeses, etc.), variations in the data may be due to assessor differences and/or product heterogeneity. The present paper proposes an approach for quantifying these two sources of variation. For individual differences, an extended version of the assessor model approach is applied. The data set used in the paper is based on sensory evaluations of three apple samples scored by a panel of 19 assessors using seven descriptors in four replicates. The application of the extended assessor model approach to unbalanced data provides more insight into assessor differences and a better test for product differences. These results demonstrate the importance of choosing the right model and taking all potential sources of variation into account.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Statistics and Data Analysis, L'Université Nantes Angers Le Mans
Authors: Bavay, C. (Ekstern), Brockhoff, P. B. (Intern), Kuznetsova, A. (Intern), Maître, I. (Ekstern), Mehinagic, E. (Ekstern), Symoneaux, R. (Ekstern)
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The assessment of produce quality is a major aspect of applied postharvest biology. Horticultural researchers working on organoleptic quality of fruit need objective methods for the evaluation of sensory properties. The development of sensory methodologies specifically for apples highlighted the problem of handling variation due to fruit variability and assessor differences. The aim of this study was to investigate the weight of within-batch variability in sensory evaluation of apples and to propose a methodology that accounts for this variability. Prior to sensory analysis, for three apple cultivars, apples were sorted into homogenous acoustic firmness categories within each cultivar. The discrimination ability of the trained panel was observed not only between cultivars but also within each cultivar for crunchiness, firmness, juiciness and acidity. Following these results, a mixed hierarchical model for the analysis of the sensory data was proposed to measure the contribution of fruit variability to the variability of sensory scores. The results showed the efficiency of the model in
quantifying within-batch variability. Fruit sampling and presentation methods as well as data handling procedures are suggested for obtaining reliable sensory results in the assessment of apple quality.

**General information**

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Organisations: Department of Applied Mathematics and Computer Science, Statistics and Data Analysis, L'Université Nantes Angers Le Mans
Authors: Bavay, C. (Ekstern), Symoneaux, R. (Ekstern), Maître, I. (Ekstern), Kuznetsova, A. (Intern), Brockhoff, P. B. (Intern), Mehinagic, E. (Ekstern)
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  - BFI (2014): BFI-level 1
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  - BFI (2013): BFI-level 1
  - Scopus rating (2013): SJR 1.581 SNIP 2.566 CiteScore 3.36
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  - BFI (2011): BFI-level 1
  - Scopus rating (2011): SJR 1.704 SNIP 2.292 CiteScore 3.06
  - ISI indexed (2011): ISI indexed yes
  - BFI (2010): BFI-level 1
  - Scopus rating (2010): SJR 2.175 SNIP 2.928
  - BFI (2009): BFI-level 1
  - Scopus rating (2009): SJR 1.912 SNIP 1.941
  - BFI (2008): BFI-level 2
  - Scopus rating (2008): SJR 1.615 SNIP 1.781
  - Scopus rating (2007): SJR 1.27 SNIP 1.888
  - Web of Science (2007): Indexed yes
  - Scopus rating (2006): SJR 1.399 SNIP 2.007
  - Scopus rating (2005): SJR 1.902 SNIP 2.97
  - Scopus rating (2004): SJR 1.213 SNIP 1.849
  - Scopus rating (2003): SJR 1.785 SNIP 3.122
  - Scopus rating (2002): SJR 1.07 SNIP 1.682
  - Scopus rating (2001): SJR 0.933 SNIP 1.743
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**ConsumerCheck: Methodology for combining sensory properties with additional information in consumer acceptance studies of food products**

Technical University of Denmark  
Period: 01/05/2010 → 21/09/2015  
Number of participants: 6  
Phd Student:  
Kuznetsova, Alexandra (Intern)  
Supervisor:  
Christensen, Rune Haubo Bojesen (Intern)  
Main Supervisor:  
Brockhoff, Per B. (Intern)  
Examiner:  
Andersen, Elisabeth Wreford (Intern)  
Højsgaard, Søren (Ekstern)  
Schlich, Pascal (Ekstern)

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Project: PhD

**Methodology for combining sensory properties with additional information in consumer acceptance studies of food products**

The project focuses on method development for better understanding of consumer acceptance of food products with added values related to health benefits, environment and user-friendliness. The main goal is to develop and make available statistical methods that can be used to identify the important factors for consumer acceptance, their interactions and their optimal combinations. This will be achieved through the following contents: 1) Statistical method development with focus on the combined use of experimental design and multivariate analysis 2) Development of an easy-to-use open source software package 3) Industry based method development, 4) writing scientific papers, giving courses and producing a PhD degree in Sensometrics. The industrial effect will be 1) lowering the costs of product development, 2) reduced product development time 3) higher hit rate of new products and 4) better predictions of product potential. Since most relevant Danish and Norwegian stakeholders are participating together with an interested international network in Netherlands, Australia and South Africa, the project will add to the already ongoing process of turning Denmark and Norway into one of the major international players for handling sensory and consumer data.

Department of Applied Mathematics and Computer Science  
Statistics and Data Analysis  
National Food Institute  
Research Group for Bioactives – Analysis and Application  
Period: 01/08/2009 → 30/04/2015  
Number of participants: 3  
Acronym: ConsumerCheck  
Project participant:  
Bruun Brockhoff, Per (Ekstern)  
Kuznetsova, Alexandra (Intern)  
Hyldig, Grethe (Intern)

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