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Paired samples CFA for the multivariate detection of change in small samples

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Abstract

Paired samples Configuration Frequency Analysis (CFA) introduced by Stemmler and Hammond (1997) is suggested as a valuable method for the multivariate detection of change in small sample designs. We examined the assumption that impulsive behavior in a Go/NoGo task, which is bivariately defined by increased speed and decreased accuracy, is not only determined by personality traits like impulsivity, but can also be manipulated by reinforcement conditions. By applying paired samples CFA we could show that impulsive behavior could be induced by positive reinforcement (reward), as well as suppressed by indirect punishment (loss of reward). We could confirm this result parametrically with an analysis of variance for repeated measures. A significant multivariate treatment effect on reaction latency and passive avoidance errors was obtained. We argue that paired sample CFA is an appropriate method for experimental and clinical small sample designs, which can be applied to data of all dignity levels (e.g. response latencies, rating scales, syndrome categories), does not imply assumptions about sample distributions, following a case oriented approach, which means that cases contributing to the significant effects can be directly identified from the cross-tabulation. In conclusion, paired samples CFA can be considered as a transparent, easy to interpret method for detecting changes in small sample within-subjects designs.

Key words: Configuration Frequency Analysis (CFA), paired samples, multivariate analysis of change, small samples

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1. Introduction

Stemmler and Hammond (1997) introduced a variant of the Configural Frequency Analysis (CFA; Lienert, 1969; von Eye, 1990) for paired samples as a distribution-free alternative to t-tests for dependent means or to analysis of variance for repeated measures. The paired samples CFA may be of value, especially, for detecting treatment effects in small sample pre-post or cross-over designs.

A paired samples design offers a number of advantages compared to completely randomized designs. Trivially, all groups compared in a within-subject design are identical at the beginning of the study. In addition, the necessary number of subjects can be reduced by using within-subjects designs. Finally, these designs are statistically more sensitive to treatment effects since error variance caused by sample differences cannot impair the effect size of the study (Ray, 1993). The disadvantages of within-subjects designs are related to their time dependency. In pre-post treatment designs it cannot be decided whether differences are real treatment effects or time related effects, i.e., carry-over effects from the experience with a prior treatment, fatigue or practice. Therefore, time related effects should be counterbalanced, e.g., by applying a crossover design with the possible treatment orders permuted between subjects. Before conducting paired samples analyses in crossover designs it has to be assured that time related effects do not interfere with the treatment order. Otherwise, the groups of subjects with different treatment order have to be analyzed separately.

We are presenting data from a small sample study testing the assumption that impulsive behavior, which is bivariately defined by increased speed and decreased accuracy, is not only determined by personality traits like impulsivity, but can also be manipulated by reinforcement conditions. We applied paired samples CFA and demonstrate the utility of this method in comparison to multivariate analysis of variance.

2. Psychometric data

In a pilot study to the dissertation thesis of the first author (Ising, 1999) we examined whether impulsive behavior can be manipulated by positive reinforcement and indirect punishment. 25 male subjects (German psychology students) were included. They had to solve twice a Go/NoGo task under different reinforcement conditions in an experimental crossover design. In the Go/NoGo task a face-like sample stimulus had to be compared with three other face-like choice stimuli on a computer monitor. When the sample matched with one of the three choice stimuli a button had to be pressed as quickly as possible (Go condition). If none of the three choice stimuli was identical with the reference no reaction had to be shown (NoGo condition), and the subject had to wait until the next trial started. Impulsive behavior is bivariately defined by increased speed and decreased accuracy, which corresponds to short reaction latencies under Go and high rate of false reactions (passive avoidance errors) under NoGo (Gorenstein & Newman, 1980; Klinteberg et al., 1990-91). All subjects conducted the trials under two experimental conditions, positive reinforcement (C^{+}) and indirect punishment ($C/^{-}$) of impulsive behavior.

13 subjects started the Go/NoGo task under C^{+} condition, that is, the subjects gained the highest amount of points when they pressed the button under Go (correct response) very quickly. The other twelve subjects conducted the task under $C/^{-}$ condition, that is, the sub-

jects lost the highest amount of points (up to four) when they pressed the button under NoGo (false response) very quickly. The three subjects with the best results won a gift certificate from a book store. After completing the trials subjects filled in questionnaires on subjective well being. Afterwards, they repeated the Go/NoGo task under the respective other experimental condition. Thus, all subjects conducted the task under both experimental conditions, the first half with the treatment order $C^+ \rightarrow C/^-$, the other half in the opposite order ($C/^- \rightarrow C^+$, crossover design).

We want to show that impulsive behavior can be induced and suppressed in a Go/NoGo task by positive reinforcement (C^+) and indirect punishment ($C/^-$), respectively. Behavior under C^+ was assumed to be predominantly characterized by short reaction latencies under Go and a high number of passive avoidance errors under NoGo. Behavior under $C/^-$, however, should be characterized by high reaction latencies under Go and a low number of passive avoidance errors under NoGo. With a paired samples approach we can rule out that different personality traits interfere with the test outcome, since the same subjects are examined under both treatment conditions.

3. Testing for carry-over effects

Before analyzing the effects of positive reinforcement and indirect punishment we examined the presence of carry-over effects, i.e., interactions between treatment order and treatment effects. For the CFA approach, we dichotomized the two dependent interval level variables, reaction latencies under Go and number of passive avoidance errors under NoGo, at the common median of both reinforcement conditions into '+' and '-' categories, and counted the frequencies of the $C^+, C/^-$ configuration of both variables separately for the two treatment orders, $C^+ \rightarrow C/^-$ and $C/^- \rightarrow C^+$ (see Table 1). Chi-square tests did not show significant interactions with treatment order, neither for Go reaction latencies (Pearson Chi² (df = 3) = 4.75, p = .191) nor for NoGo passive avoidance errors (Pearson Chi² (df=3) = 5.55, p = .136). We additionally calculated exact Fisher tests for all configuration frequencies (++, +-, -+, --) by cross-classifying the frequencies of the two treatment orders for each of the four configurations with the sum of the respective three other configurations. The level of significance was adjusted to 0.0125 due to the fourfold testing in order to protect the experimentwise alpha level of 0.05. The results are presented in Table 1.

No significant differences in $C^+, C/^-$ configuration frequencies between both treatment orders were observed suggesting that the combined analysis of both treatment orders is justified in the configural approach.

We additionally performed an analysis of variance separately for the two response variables, reaction latencies under Go and passive avoidance errors under NoGo. Box M and separate Levene tests did not indicate a violation of the assumption of homogeneity between the two independent treatment order groups ($p > .10$). We did not observe significant interaction effects between treatment order and treatment effects for Go reaction latencies ($F_{1,23}$ = 1.27, p = .271). However, a significant interaction was found for the NoGo passive avoidance errors ($F_{1,23}$ = 6.74, p = .016) indicating a semi-disordinal effect with increased error

Table 1:
Configuration frequencies of Go reaction latencies and of NoGo passive avoidance errors under C^+ and $C/-$ condition for both treatment orders

Go-Reaction Latencies			
C^+ $C/^-$	$C^+ \to C/^-$	$C/^- \to C^+$	p (Fisher)
+ +	5	1	.194
+ -	1	0	1.000
- +	4	5	.880
- -	3	6	.326
	13	12	N = 25
Passive Avoidance Errors			
C^+ $C/^-$	$C^+ \to C/^-$	$C/^- \to C^+$	p (Fisher)
+ +	4	1	.371
+ -	2	7	.067
- +	1	2	1.000
- -	6	3	.496
	13	12	N = 25

rate under C^+ only in the $C/^- \to C^+$ but not in the $C^+ \to C/^-$ group. We combined both treatment order groups for the subsequent comparison with paired samples CFA, although a carry over effect cannot be ruled out for NoGo passive avoidance errors. However, the treatment effects of the two order groups are not disordinal, but present only in one of the two order groups (semi-disordinal interaction), which means that merging of both treatment order groups might weaken but not invalidate the results for this variable.

4. Assessment of treatment effects with paired samples CFA and MANOVA

We assume that behavior under reinforcement (C^+) condition should be characterized by short reaction latencies under Go *and* a high number of passive avoidance errors under NoGo. On the other hand we suppose that behavior under indirect punishment ($C/^-$) condition should be characterized by high reaction latencies under Go *and* a low number of passive avoidance errors under NoGo. Therefore, we need a bivariate perspective in our statistical analysis since we are assuming change in both dependent variables simultaneously. Behavioral variables frequently present with a multimodal distribution which is a violation of an important prerequisite for parametric analysis. Paired samples CFA as suggested by Stemmler and Hammond (1997) is a promising approach for this kind of analysis, since (1) it does not imply assumptions about the distribution of the variables (distribution-free), and (2) it is a multivariate approach with variables combined to configurations.

Paired samples CFA requires that the categories of both variables are paired to a 2 x 2 - dimensional configuration with both experimental conditions ($C^+/C/^-$) cross-classified. The configuration frequencies of the resulting (2 x 2) x (2 x 2) square contingency table are shown in Table 2.

Table 2:
Configuration frequencies of Go reaction latencies (L) and NoGo passive avoidance errors (E) under C^+ and $C/^-$ condition

		$C/^-$				
	L E	+ +	+ −	− +	− −	R
C^+	+ +	0	1	0	1	2
	+ −	0	5	0	0	5
	− +	2	4	3	3	12
	− −	1	2	1	2	6
	C	3	12	4	6	N = 25

We compare each of the four behavioral reaction patterns (++, +−, −+, −−) pairwise between the C^+ and $C/^-$ condition according to Lehmacher's marginal homogeneity sign test (Lehmacher, 1980). The Lehmacher test requires the elimination of the no-change cases located in the cells of the main diagonal of Table 2, since they do not contribute to a change-related test hypothesis (see Siegel & Castellan, 1988, Ch. 5.2). Therefore, we need to calculate corrected marginals $F_{i.}$ and $G_{.i}$ for all of the four behavioral reaction patterns

$$F_{i.} = R_{i.} - f_{ii},$$
$$G_{.i} = C_{.i} - f_{ii},$$

with $R_{i.}$ / $C_{.i}$ = row/column marginals, f_{ii} = main diagonal frequencies, and i = 1 (1) 4. The resulting frequencies of $F_{i.}$ and $G_{.i}$ are shown in Table 3. $F_{i.}$ corresponds to the number of changes from the i^{th} reaction pattern under C^+ to any other under $C/^-$, $G_{.i}$ corresponds to the number of changes from the i^{th} reaction pattern under $C/^-$ to any other under C^+.

Table 3:
Paired samples CFA with Go reaction latencies (L) and NoGo passive avoidance errors (E) under C^+ and $C/^-$ condition

L E	$F_{i.}(C^+)$	$G_{.i}(C/^-)$	p (Fisher)
+ +	2 – 0 = 2	3 – 0 = 0	1.000
+ −	5 – 5 = 0	12 – 5 = 7	.006
− +	12 – 3 = 9	4 – 3 = 1	.005
− −	6 – 2 = 4	6 – 2 = 4	1.000
Σ	15	15	

Under the Null-Hypothesis (H_0) of no change between the two experimental conditions the corrected table marginals $F_{i.}$ and $G_{.i}$ are identical for all of the four reaction patterns. We test the H_0 of no change between the two experimental conditions with Lehmacher's marginal sign test. It can be performed exactly by applying the Fisher test for each of the r = 4 rows in Table 3. We cross-classified the two corrected marginals for each of the four reaction patterns with the sum of the respective three other patterns, and calculated exact Fisher tests for the resulting 2 x 2 tables.

Without specifying an alternative to H_0 we need to correct for multiple testing in order to protect experiment-wise alpha. We applied the Bonferroni procedure and adjusted the significance level α^* to .0125 (0.05/4). We see from Table 3 that subjects showing high Go reaction latencies and a low rate of passive avoidance errors under NoGo are typical for the $C/^-$ condition (7 vs. 0, p = .006), while the complementary pattern (low reaction latencies and a high rate of passive avoidance errors) is characteristic for C^+ (9 vs. 1, p = .005).

We additionally conducted a multivariate analysis of variance (MANOVA) with reaction latencies under Go and passive avoidance errors under NoGo as dependent variables and the treatment conditions C^+ vs. $C/^-$ as repeated measures factor. Since we assume simultaneous treatment effects on both dependent variables we focused on the multivariate Wilks' Lambda test, which was significant with a Lambda of .628 and a resulting $F_{2,23}$ score of 6.82 ($p < .006$). Mean value of the two dependent variables descriptively suggest a similar outcome pattern as detected with the paired samples CFA, i.e., decreased Go reaction latencies combined with an increased rate of NoGo passive avoidance errors under C^+ compared to $C/^-$.

5. Discussion

By applying paired samples CFA we could show that impulsive behavior in a Go/NoGo task, which is defined by a pattern of short Go reaction latencies and elevated rate of NoGo passive avoidance errors, could be induced by positive reinforcement (reward), as well as suppressed by indirect punishment (loss of reward). This confirms our assumption that impulsive behavior is not only determined by personality traits like impulsivity (Klinteberg et al., 1990-91) but also by situational determinants like reinforcement and punishment conditions. We could confirm this result parametrically with an analysis of variance. A significant multivariate treatment effect on reaction latency and passive avoidance errors was obtained.

Albeit parametric tests can be regarded as superior in power, the following points underscore the utility of configural approaches like the paired samples CFA in experimental and clinical small sample designs: (1) Paired samples CFA is applicable to data of all dignity levels (e.g. response latencies, rating scales, syndrome categories), and (2) it is distribution-free, that is, there are no assumptions about the underlying sample distribution. Another advantage of paired samples CFA compared to parametric and also other non-parametric methods (e.g., like log linear modeling) is that it follows (3) a case oriented approach (Bergman et al., 1991; Magnusson, 1985), which means that cases contributing to the significant effects can be directly identified from the cross-tabulation.

We conclude that paired samples CFA can be considered as a transparent, easy to interpret method for detecting changes in small sample within-subjects designs.

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