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Research report

Comparing a single case to a control sample: Testing for neuropsychological deficits and dissociations in the presence of covariates

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ABSTRACT

Existing inferential methods of testing for a deficit or dissociation in the single case are extended to allow researchers to control for the effects of covariates. The new (Bayesian) methods provide a significance test, point and interval estimates of the effect size for the difference between the case and controls, and point and interval estimates of the abnormality of a case's score, or standardized score difference. The methods have a wide range of potential applications, e.g., they can provide a means of increasing the statistical power to detect deficits or dissociations, or can be used to test whether differences between a case and controls survive partialling out the effects of potential confounding variables. The methods are implemented in a series of computer programs for PCs (these can be downloaded from www.abdn.ac.uk/~psy086/dept/Single_Case_Covariates.htm). Illustrative examples of the methods are provided.

1. Introduction

The focus of the present paper is on single-case studies in neuropsychology that employ the case–controls design; i.e., studies in which inferences concerning the cognitive performance of a single-case are made by comparing the case to a sample of healthy controls. Crawford, Garthwaite, Howell and colleagues (Crawford and Howell, 1998a; Crawford and Garthwaite, 2002, 2005, 2007a) have developed a set of classical and Bayesian methods for this design. These methods allow researchers to test for a deficit in the single-case, and to test whether the standardized difference between a case's score on two tasks differs from the differences observed in controls; the latter methods are useful in testing for dissociations (Crawford et al., 2003; see Crawford and Garthwaite, 2007a for further details).

Although these methods are sound and useful they do not currently offer solutions to some of the more complex issues faced by the single-case researcher. The aim of the present paper is to extend upon these existing methods to allow researchers to test for deficits or dissociations while controlling for the effects of covariates. That is, the aim is to develop a Bayesian Test for a Deficit allowing for Covariates (BTD-Cov) and a Bayesian Standardized Difference Test allowing for Covariates (BSDT-Cov).

These new methods can serve the broad purpose of allowing researchers to control for nuisance variables when comparing a case to controls. When a healthy control sample

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is recruited to match a single case, the controls are intended to represent the case minus the lesion. The controls should therefore be closely matched on as many potentially important attribute variables as possible. For example, performance on many neuropsychological tasks is moderately-to-highly correlated with age and educational level and, for some cognitive functions, gender may also exert an influence on performance. In practice it can be difficult and time-consuming to recruit an adequately matched sample, particularly if a researcher wants to match the controls on cognitive variables as well as on demographic/attribute variables. Indeed it is obvious from even a casual inspection of published single-case studies that matching is often sub-optimal. One could adopt a pious attitude to these difficulties: the researcher should simply work harder to find more suitable controls. However, the methods developed in the present paper offer a practical alternative when such attempts have failed. Note also that it is not uncommon for researchers to use a single control group as a reference sample for the comparison of the performance of multiple single cases; the methods set out here can play a particularly useful role in such comparisons (see the Discussion section for a fuller treatment of this issue).

The methods can also be used for two, more targeted, purposes: First, they can be used to increase the power to detect a deficit or dissociation in a single case by controlling for the effects of a suppressor variable. A suppressor variable in this context can be defined as any variable that obscures or attenuates the difference between the case and controls. The issue of the statistical power of inferential methods for the single-case has been largely neglected (Crawford and Garthwaite, 2006b). However, it is clear that statistical power will typically be lower than that found in group studies in neuropsychology: a single case, rather than a clinical sample, is compared to a control group and, moreover, the control groups typically employed are modest in size. As sample size is an important determinant of power, it can be seen that power will be low unless effects are very large (neurological damage can have dramatic consequences on cognition and so of course large effects are often there to be detected). Therefore, anything that can increase statistical power to detect deficits or dissociations should be encouraged (provided that it does not achieve this at the cost of failing to control the Type I error rate).

Furthermore, the methods can be used to test whether a difference in task performance between a single case and controls can be explained by the effects of a third variable. That is, in contrast to the foregoing potential application, the methods can also be used to test whether differences survive controlling for the effects of covariates. For example, a difference between a case and controls on a task of interest may be attributable to a general slowing of information processing rather than impairment of the putative specific function measured by the task. This possibility could be approached by testing for a deficit on the task while controlling for a measure of processing speed.

1.1. *Testing for deficits and dissociations in the presence of covariates: desirable statistics*

The statistical methods developed previously by Crawford, Garthwaite, Howell and colleagues provide a comprehensive set of statistics. For example, when testing for the presence of a deficit the methods provide a significance test – if the p value from this test (Crawford and Howell, 1998a) is below the specified value for alpha (normally .05) then the researcher can reject the null hypothesis that the case's score is an observation from the scores in the control population. The p value from this test is also the optimal point estimate of the abnormality of the case's score (i.e., it is the estimated proportion of controls that will obtain a score lower than the case; multiplying this figure by 100 gives the percentage of controls expected to obtain a lower score). Thus, if the p value is .0240, then only 2.4% of controls are expected to obtain a lower score. For a mathematical proof of this dual role for the p value see Crawford and Garthwaite (2006b).

Crawford and Garthwaite (2002) have developed methods that supplement the point estimate of the abnormality of the case's score with an interval estimate of the same quantity. Such an interval estimate is in keeping with the contemporary emphasis in both psychology and statistics on the provision of confidence intervals. Finally, Crawford et al. (2010) have emphasized the importance of reporting point and interval for effect sizes in single-case studies and provided methods for achieving this.

Fortunately it will be possible to provide the direct equivalents of all of these statistics when controlling for the effects of covariates. The meaning of these statistics will remain broadly the same but with some important differences. That is, the significance test will still test if we can reject the null hypothesis that the case's score is an observation from the scores in the control population, but the control population is redefined as controls having the same value(s) on the covariate(s) as the case. Similarly, the point estimate of the abnormality of the case's score on the task of interest is the percentage of controls, with the same value(s) on the covariate(s), that are expected to obtain a lower score than the case. To develop these methods we extend Crawford and Garthwaite's (2007a) Bayesian approach to the analysis of the single case.

2. Method

2.1. *Bayesian method of testing for a deficit or dissociation controlling for covariates*

We assume that, conditional on the values of the covariates, in the control population the task(s) of interest follow either a normal distribution (when there is only one task of interest, i.e., when we wish to test for a deficit) or a bivariate normal distribution (when there are two tasks of interest, i.e., when we wish to test for a dissociation); see later section for a discussion of these assumptions. No assumptions are made about the distribution of the covariates and, indeed, their values need not be random as will happen, for example, with some experimental designs. We have a control sample of n individuals with scores on k tasks and values for m covariates from which to estimate $\mathbf{B} = (\underline{\beta}_1, \ldots, \underline{\beta}_k)$, where $\underline{\beta}_i$ is the vector of $m+1$ regression coefficients that relates the ith task to the covariates in the control population, and Σ, a $k \times k$ matrix of the control population covariances for the scores on tasks,