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DICHOTOMIZED_D: A SAS® Macro for Computing Effect Sizes for Artificially Dichotomized Variables

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ABSTRACT

Measures of effect size are recommended to communicate information on the strength of relationships between variables, providing information to supplement the reject / fail-to-reject decision obtained in statistical hypothesis testing. With artificially dichotomized response variables, seven methods have been proposed to estimate the standardized mean difference effect size that would have been realized before dichotomization. This paper provides a SAS macro for computing these seven effect size estimates by utilizing data from PROC FREQ output data sets. The paper provides the macro programming language, as well as results from an executed example of the macro.

Keywords: EFFECT SIZES, DICHOTOMIZED VARIABLES, BASE SAS, SAS/STAT

INTRODUCTION

The topic of effect sizes can be a controversial issue for many journal editors, as well as for researchers. For instance, Pedhazur and Pedhazur-Schmelking (1991) argued that Cohen's (1988) convention of small, medium, and large effect sizes distorted the distinction between the magnitude of an effect and its substantive importance, i.e., researchers relegating "small" effects as less important or considering "large" effects as important. Also, the use and interpretation of a specific effect size across studies can be problematic due to the variability of research design factors, the last edition of the *Publication Manual of the American Psychological Association* (6th edition; 2010) as well as the 1999 report by Wilkinson and the APA Task Force on Statistical Inference have made clear the imperative for reporting effect sizes to supplement statistical hypothesis testing and ensure "accuracy of scientific knowledge" (p. 11). Effect sizes provide useful indices of the magnitudes of treatment effects in individual studies as well as representing the primary statistics that are used in synthesizing research or meta-analysis.

Cohen (1977) defined effect size (ES) as "the degree to which the phenomenon is present in the population" (pp. 9-10), or "the degree to which the H_0 is believed to be false" (1992; p. 156). Each statistical test has its own ES index, which is scale free and continuous; however, to convey meaning of any ES index, it is necessary to have an idea of its scale, for which he proposed the small, medium, and large ES conventions.

One ES index of mean differences is d . That is, for studies comparing two groups on a continuous outcome variable, the standardized mean difference (also referred to as Cohen's d) is the most common index of effect size. In a population, this ES is obtained as

$$\delta = \frac{\mu_E - \mu_C}{\sigma}$$

where μ_E and μ_C are the means of the experimental and control populations, respectively, and σ is the common population standard deviation.

A sample estimate of this effect size (d) is obtained by substituting sample statistics for each of these parameters. The sampling variance of this estimate is given by

$$S_d^2 = \frac{n_E + n_C}{n_E n_C} + \frac{d^2}{2(n_E + n_C)}.$$

In medical and social science research, continuous outcome variables are often dichotomized using a cut score to delineate the two dichotomous values. For example, measures of blood pressure or depression may be obtained on a continuous scale, but are subsequently dichotomized to classify patients as hypertensive or clinically depressed. Similarly, educational achievement measures may be obtained as a continuous variable (number of test items correct or scale score on a standardized achievement test) and subsequently dichotomized into pass / fail. With such dichotomization, the standardized mean difference can no longer be directly estimated from sample data. A variety of statistics have been proposed to provide estimates of the standardized mean difference that would have

been obtained if the data had not been dichotomized. These effect sizes have been compared in Monte Carlo studies reported by Sanchez-Meca, Marín-Martínez and Chacón-Moscoso, (2003), and by Kromrey and Bell (2012).

ALTERNATIVE METHODS FOR COMPUTING DICHOTOMIZED EFFECT SIZES

The standardized proportion difference (d_p ; Johnson, 1989) is a direct analogy to the standardized mean difference

$$d_p = \frac{P_E - P_C}{S'}$$

where P_E and P_C are the sample success (or failure) proportions of the experimental and control groups. The pooled standard deviation is obtained as

$$S' = \sqrt{\frac{(n_E - 1)P_E(1 - P_E) + (n_C - 1)P_C(1 - P_C)}{n_E + n_C - 2}}$$

The sampling variance of this statistic is obtained as

$$S_{d_p}^2 = \frac{n_E + n_C}{n_E n_C} + \frac{d_p^2}{2(n_E + n_C)}$$

The phi coefficient (Φ) is commonly used as a measure of association for 2 X 2 tables. This index can be transformed to the scale of the standardized mean difference (Rosenthal, 1994). The phi coefficient is obtained as

$$\Phi = \frac{O_{1E}O_{2C} - O_{2E}O_{1C}}{\sqrt{n_E n_C m_1 m_2}}$$

where the O_{iE} and O_{iC} are the success and failure frequencies in the experimental and control groups, respectively, and the m_i are the marginal success and failure frequencies.

The transformation of Φ to the standardized mean difference metric is given by

$$d_\Phi = \frac{\Phi}{\sqrt{1 - \Phi^2}} \sqrt{\frac{(n_E + n_C - 2)(n_E + n_C)}{n_E n_C}}$$

with sampling variance

$$S_{d_\Phi}^2 = \frac{n_E + n_C}{n_E n_C (1 - \Phi^2)^2}$$

An arcsine transformation of the proportions in a 2 X 2 table was suggested by Cohen (1988)

$$d_{asin} = 2 \arcsin(\sqrt{P_E}) - 2 \arcsin(\sqrt{P_C})$$

with sampling variance

$$S_{d_{asin}}^2 = \frac{1}{n_E} + \frac{1}{n_C}$$

Hasselblad and Hedges (1995) suggested a transformation of the log odds ratio to the metric of the standardized mean difference

$$d_{HH} = \text{Ln}(OR) \frac{\sqrt{3}}{\pi}$$

with sampling variance

$$S_{d_{HH}}^2 = \frac{3}{\pi^2} \left(\frac{1}{O_{1E}} + \frac{1}{O_{2E}} + \frac{1}{O_{1C}} + \frac{1}{O_{2C}} \right)$$

A similar transformation of the log odds ratio was proposed by Cox (1970)

$$d_{Cox} = \frac{\text{Ln}(OR)}{1.65}$$

with sampling variance

$$S_{d_{Cox}}^2 = 0.367 \left(\frac{1}{O_{1E}} + \frac{1}{O_{2E}} + \frac{1}{O_{1C}} + \frac{1}{O_{2C}} \right).$$

Glass, McGaw, and Smith (1981) proposed a probit transformation to obtain an effect size in the metric of the standardized mean difference

$$d_{Probit} = Z_E - Z_C$$

where Z_E and Z_C are the inverse of the standard normal distribution for P_E and P_C , respectively. That is,

$$Z_i = \Phi^{-1}(P_i).$$

The sampling variance of d_{Probit} can be estimated by

$$S_{d_{Probit}}^2 = \frac{2\pi P_E(1-P_E)e^{Z_E^2}}{n_E} + \frac{2\pi P_C(1-P_C)e^{Z_C^2}}{n_C}.$$

A final index is obtained by transforming the biserial-phi correlation coefficient into the metric of the standardized effect size (Becker & Thorndike, 1988). The biserial-phi coefficient is obtained as

$$\Phi_{bis} = \frac{\sqrt{p'q'}}{y'} \Phi$$

where p' and q' are the marginal success and failure proportions from the 2 X 2 table, and y' is the ordinate of the standard normal distribution at p' .

The biserial-phi coefficient is transformed to the scale of the standardized mean difference using

$$d_{bis} = \frac{\Phi_{bis}}{\sqrt{1-\Phi_{bis}^2}} \sqrt{\frac{(n_E + n_C - 2)(n_E + n_C)}{n_E n_C}}$$

with sampling variance

$$S_{d_{bis}}^2 = \frac{p'q'(1-\Phi_{bis}^2)(n_E + n_C)}{y'^2 n_E n_C (1-\Phi_{bis}^2)^3}.$$

These indices were compared in a simulation study by Sanchez-Meca et al. (2003). The authors varied the sample sizes for the two groups, the cut points for dichotomization, and the population effect size, but maintained homogeneous variances in the two groups. The results suggested that d_{Cox} and d_{Probit} provided nearly unbiased estimates of the population effect size δ . This research was replicated and extended by Kromrey and Bell (2012) who investigated heterogeneous variance conditions in addition to the homogeneous variance conditions studied by Sanchez-Meca et al. (2003). In the latter study, the Cox and Probit effect sizes showed smallest bias overall, but this advantage was limited to conditions in which population variances were equal. Under heterogeneous variances, all indices evidenced similar patterns of bias associated with changes in the cut point for dichotomization. An evaluation of the sampling errors of these indices or a consideration of the RMSE (which combines sampling error and bias into a metric of total error) suggested that the standardized proportion difference, the transformed phi coefficient, and the arcsine transformation have smaller sampling errors and smaller total errors than the Cox and Probit indices. These advantages were especially pronounced at smaller sample sizes and with populations presenting smaller effect sizes.

MACRO DICHOTOMIZED_D

The SAS macro DICHOTOMIZED_D provides calculations of the seven effect size indices described above, as well as their sampling variances. The macro is written in BASE SAS and makes use of output data files from PROC

FREQ to produce a SAS data set within which the effect sizes and their variances are computed. The arguments to the macro are the name of the SAS data set that contains the data to be analyzed (indata), the names of the grouping and outcome variables (group_var and result_var), the binary values of these two variables (group1, group2, result1, and result2), and two arguments to indicate the use of weights (haswgt and wgtvar). The macro output is a simple table that provides details on the sample and the resulting effect size indices.

```
%macro dichotomized_d (indata=_LAST_, group_var =, result_var =, group1=, group2=,
  result1=, result2=, haswgt= N, wgtvar=);

* +-----+
  Create SAS data & evaluate the variable types and use of weights
* +-----+;

data _one;
  set &indata;

  %if &haswgt = Y %then %do;
    wgt = &wgtvar;
  %end;
  %if &haswgt = N %then %do;
    wgt = 1;
  %end;

  if &group_var = "&group1" then groups = "E";
  else if &group_var = "&group2" then groups = "C";
  if &result_var = "&result1" then decisions = "P";
  else if &result_var = "&result2" then decisions = "F";

run;

proc freq data=_one noprint;
  weight wgt;
  tables groups*decisions / out=_a outpct;
run;

* +-----+
  Print cell frequencies
* +-----+;

options nodate nonumber;
ods noproctitle;
%if &haswgt = Y %then %do;
  proc freq data = &indata;
    title 'Cell Frequencies';
    tables &result_var*&group_var / norow nocol nopercnt;
    weight &wgtvar;
  run;
%end;
%if &haswgt = N %then %do;
  proc freq data = &indata;
    title 'Cell Frequencies';
    tables &result_var*&group_var / norow nocol nopercnt;
  run;
%end;
title '  ';

data _a ;
  set _a ;
  id = groups || decisions;

* +-----+
  Prepare a dataset with zero frequencies to check for missing cells
* +-----+;

%let ids = CF CP EF EP;
data _b;
```

```

%do v=1 %to 4;
  %let idd = %scan(&ids,&v);
  id = "&idd";
  groups = substr("&idd",1,1);
  decisions = substr("&idd",2,1);
  count = .;
  percent = .;
  pct_row = .;
  pct_col = .;
  output;
%end;
run;

* +-----+
  Create a dataset with adjusted frequencies: if at least one cell has
  frequency of zero, add 0.5 to each cell
* +-----+;

proc sort data=_a; by id;
proc sort data=_b; by id;

data _two;
  merge _b _a ;
  by id;
  cnt = .5;

proc sort data=_two; by cnt count; run;

data _two;
  set _two;
  retain mscnt;
  by cnt;
  if first.cnt then mscnt = count;
  if mscnt = . then do;
    if count = . then frq = cnt;
    else frq = count + cnt;
  end;
  else frq = count;

  if id = "CF" then call symputx("CFold",count);
  if id = "CP" then call symputx("CPold",count);
  if id = "EF" then call symputx("EFold",count);
  if id = "EP" then call symputx("EPold",count);

  if id = "CF" then call symputx("CF",frq);
  if id = "CP" then call symputx("CP",frq);
  if id = "EF" then call symputx("EF",frq);
  if id = "EP" then call symputx("EP",frq);

* +-----+
  Calculate table elements using adjusted frequencies
* +-----+;

data _three;
  ocf = &CFold;
  ocp = &CPold;
  oef = &EFold;
  oep = &EPold;
  array actual(4) ocf ocp oef oep;

  do i = 1 to 4;
    if actual(i)=. then actual(i)=0;
  end;

  ncf = &CF;
  ncp = &CP;

```

```

nef = &EF;
nep = &EP;
total = sum (of ncf ncp nef nep);
rowc = sum (of ncf ncp);
rowe = sum (of nef nep);
pcf = ncf/total;
pcp = ncp/total;
pef = nef/total;
pep = nep/total;
rcp = ncp/rowc;
rep = nep/rowe;
nc = ncf + ncp;
ne = nef + nep;

* +-----+
  Checking for invalid patterns of missing cells. If found, abort execution
  and print message.
* +-----+;

error = . ;
if ocf + ocp = 0 then error = 1;
if oef + oep = 0 then error = 1;
if ocf + oef = 0 then error = 1;
if ocp + oep = 0 then error = 1;
call symputx("error", error);
run;

%if &error = 1 %then %do;
  %put "Please check data.";
  data _null_;
  file print notitles;
  put @1 'Please check data.' /
      'Effect size indices cannot be computed from this data table.';
  return;
run;
%return;
%end;

data _three;
  set _three;

* +-----+
  Computing the standardized proportion differences
* +-----+;

s_prime = sqrt(((ne-1)*rep*(1-rep)+(nc-1)*rcp*(1-rcp))/(ne+nc-2));
d_p = (rep - rcp)/s_prime;
var_d_p = (ne + nc)/(ne*nc) + d_p**2/(2*(ne+nc));

* +-----+
  Computing standardized phi coefficient
* +-----+;

phi = (nep*ncf-nef*ncp)/sqrt(ne*nc*(nep+ncp)*(nef+ncf));
d_phi = phi/sqrt(1-phi**2)*sqrt(((ne+nc-2)*(ne+nc))/(ne*nc));
var_d_phi = (ne+nc)/(ne*nc*(1-phi**2)**2);

* +-----+
  Computing standardized arcsin transformation d
* +-----+;

d_asin = 2*arsin(sqrt(rep))-2*arsin(sqrt(rcp));
var_d_asin = 1/ne + 1/nc;

* +-----+
  Computing odds ratio based effect size

```

```

* +-----+;

or = (rep*(1-rcp))/(rcp*(1-rep));
pi = constant('PI');
d_HH = log(or)*(sqrt(3)/pi);
var_d_HH = (3/pi**2)*(1/nep+1/ncp+1/nef+1/ncf);

* +-----+
  Computing Cox effect size
* +-----+;

d_Cox = log(or)/1.65;
var_d_Cox = 0.367*(1/nep+1/ncp+1/nef+1/ncf);

* +-----+
  Computing probit effect size
* +-----+;

d_probit = probit(rep) - probit(rcp);
var_d_probit = (2*pi*rep*(1-rep)*exp(probit(rep)**2))/ne +
              (2*pi*rcp*(1-rcp)*exp(probit(rcp)**2))/nc;

* +-----+
  Computing biserial-phi coefficient
* +-----+;

p_prime = pep + pcp;
q_prime = 1 - p_prime;
ordinate = pdf('NORMAL',PROBIT(p_prime));
phi_bis = sqrt(p_prime*q_prime)/ordinate*phi;
if phi_bis > .99 then phi_bis = .99;
if phi_bis < -.99 then phi_bis = -.99;
d_bis = (phi_bis/sqrt(1-phi_bis**2))*sqrt(((ne+nc-2)*(ne+nc))/(ne*nc));
var_d_bis = (p_prime*q_prime*(1-phi_bis**2)*(ne+nc))/
            (ordinate**2*ne*nc*(1-phi_bis**2)**3);

data _null_;
  set _three;

* +-----+
  Print output using FILE PRINT
* +-----+;

file print notitles;
put @1 'Estimated Effect Sizes for Dichotomized Variables' //
    @1 'Index' @50 'Value' @65 'Variance' /
    @1 '-----' @49 '-----' @64 '-----' /
    @1 'Standardized Proportion Difference' @50 d_p 8.4 @65 var_d_p 8.4 //
    @1 'Standardized Phi' @50 d_phi 8.4 @65 var_d_phi 8.4 //
    @1 'Arcsine D' @50 d_asin 8.4 @65 var_d_asin 8.4 //
    @1 'dHH' @50 d_HH 8.4 @65 var_d_HH 8.4 //
    @1 'Cox Effect Size' @50 d_Cox 8.4 @65 var_d_Cox 8.4 //
    @1 'Probit Effect Size' @50 d_probit 8.4 @65 var_d_probit 8.4 //
    @1 'Biserial-Phi Coefficient' @50 d_bis 8.4 @65 var_d_bis 8.4;
run;

* +-----+
  Clean up workspace: remove data sets created by the macro
* +-----+;

proc datasets;
  delete _one _two _three _a _b; quit;
%mend;

```

INVOKING THE MACRO

To better demonstrate how to use this macro, we will illustrate three datasets and associated calls to the macro. Dataset ONE uses alphanumeric variables for both treatment group and result. The arguments to the macro include the name of the SAS dataset (indata=one), the group variable (group_var=grp), and the result variable (result_var=decision). In addition, arguments specify the coding for grp and decision used in the dataset (group1=grp1, group2=grp2, result1=good, result2=bad).

```
data one;
    input id grp $ decision $ ;
cards;
1 grp1 good
2 grp1 bad
3 grp2 good
4 grp2 good
.
.
;
%DICHOTOMIZED_d (indata=ONE,group_var=grp,result_var=decision,group1=grp1,
    group2=grp2, result1=good, result2=bad);
```

For dataset TWO that uses numeric variables, the corresponding arguments to the macro should be the same as those for Dataset ONE, except for specifying the coding of the two numeric variables (group1=1, group2=2, result1=1, result2=2).

```
data two;
    input id grp decision ;
cards;
1 1 1
2 1 2
3 2 1
4 2 1
.
.
;
%DICHOTOMIZED_d (indata=two,group_var=grp,result_var=decision,group1=1,group2=2,
    result1=1,result2=2);
```

Dataset THREE illustrates the use of weights in calling the macro. This dataset has one row for each cell of the corresponding table, and a variable to indicate the number of observations in each cell. Because alphanumeric variables are used for grp and decision, the arguments are the same as those used for Dataset ONE, except for two additional arguments. One argument indicates that weights are used (haswgt=yes) and the other defines the name of the weight variable (wgtvar=frq). The output of the DICHOTOMIZED_D macro is presented in the next section.

```
data three;
    input grp $ decision $ frq;
    cards;
grp1 good 50
grp2 good 39
grp1 bad 20
grp2 bad 14
;
%DICHOTOMIZED_d (indata=three,group_var=grp,result_var=decision,group1=grp1,
    group2=grp2,result1=good,result2=bad,haswgt=Y,wgtvar=frq);
```

OUTPUT FROM MACRO FOR DICHOTOMIZED EFFECT SIZES

Prior to displaying the effect sizes, the macro presents a two-dimensional frequency table providing the cell and marginal frequencies for the input data (Output 1). This table allows verification of the accuracy of the data being analyzed.

```

Cell Frequencies

                                Table of decision by grp

                                decision      grp

                                Frequency,grp1      ,grp2      , Total
                                ffffffff^fffffff^fffffff^
                                bad      ,      4      ,      3      ,      7
                                ffffffff^fffffff^fffffff^
                                good      ,      5      ,      7      ,      12
                                ffffffff^fffffff^fffffff^
                                Total      9      10      19

```

Output 1. A 2 by 2 Output Data File Generated Using PROC FREQ

The computed effect sizes and their variances are presented in a simple table (Output 2). In this example, the values of the estimated population effect sizes range between -.29 for Standardized Phi to -.38 for the Probit effect size. Note the Standardized Phi is the smallest effect size. The seven measures of effect size all fall within the same general range and are considered small population effect sizes (Cohen, 1977, 1988). The estimates for the variances of the effect sizes range between .21 for the Standardized Proportion Difference and Arcsine D and .38 for the Biserial-Phi coefficient. These are large variances; however, this is expected when the sample size is small.

Estimated Effect Sizes for Dichotomized Variables		
Index	Value	Variance
Standardized Proportion Difference	-0.3029	0.2135
Standardized Phi	-0.2865	0.2209
Arcsine D	-0.3002	0.2111
dHH	-0.3441	0.2815
Cox Effect Size	-0.3783	0.3399
Probit Effect Size	-0.3847	0.3495
Biserial-Phi Coefficient	-0.3692	0.3778

Output 2. Estimated Effect Sizes for Dichotomized Variables

COMPARISON OF DICHOTOMIZED EFFECT SIZES FOR ACCURACY AND PRECISION

Kromrey and Bell (2012) investigated the accuracy and precision of the seven effect size indices using simulation methods. The Monte Carlo study investigated (a) overall sample size ($n_1 + n_2 = 30, 60, 120, 240$), (b) ratio of sample sizes in the two groups (1:1, 1:2, 1:4), (c) population effect size (0, .2, .5, .8), (d) continuous score cut point for dichotomization (.10, .25, .40, .70), and (e) population variance ratio (1:1, 1:2, 1:3). For each condition, 100,000 replications were conducted. Using SAS/IML, normally distributed, continuous data were generated for two groups and the continuous variables were dichotomized at the specified cut points. In each sample, the standardized mean difference was computed prior to dichotomization and the seven effect size indices were computed after the data were dichotomized.

SIMULATION RESULTS

The overall distributions of statistical bias across all simulation conditions are presented as box and whisker plots in Figure 1. All seven indices tended to be negatively biased in their estimation of the effect size, yielding an effect size index that was smaller on average than the population effect size. Overall, the Cox, Probit, and biserial-phi indices evidenced notably smaller bias than the other indices, although the variability in the bias of the biserial-phi index was large relative to the others.

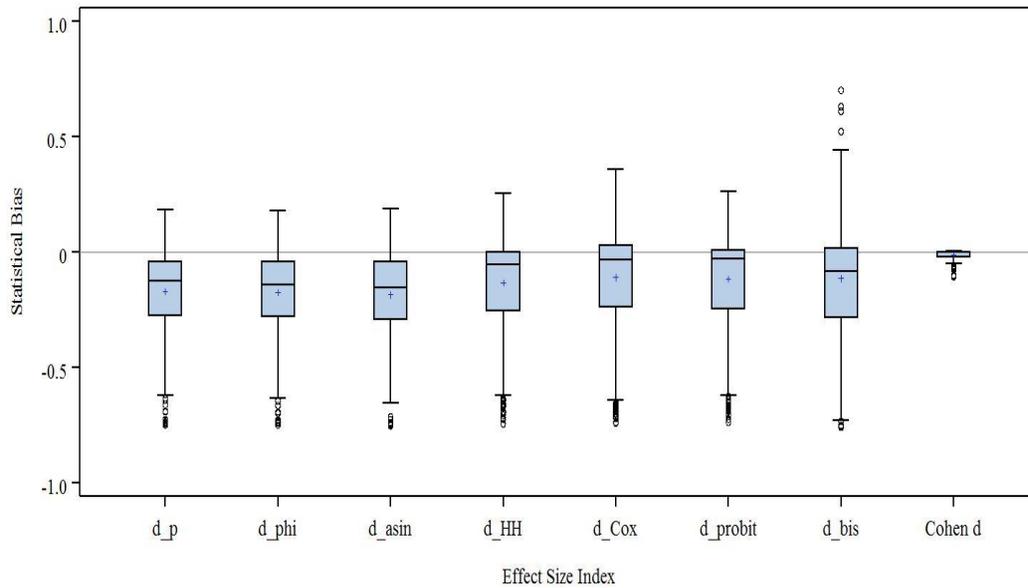


Figure 1. Distributions of Statistical Bias Estimates

In addition to the estimates of statistical bias, the sampling errors of the effect sizes were evaluated. The distributions of the empirical variances of the effect size indices across all conditions investigated in the simulation are presented in Figure 2. The average variances of the standardized proportion difference, the transformed phi coefficient, and the arcsine transformation were only slightly larger than the average variance of Cohen's d effect size. In contrast, the other effect size indices yielded average variances that were nearly twice as large as these. Finally, the biserial-phi index evidenced exceptionally large sampling variance in many conditions.

The Root Mean Squared Error (RMSE) combines the bias and the standard error, resulting in the total error expected in a single sample estimate of the effect size. The distributions of RMSE across all simulation conditions are presented in Figure 3. In contrast to the statistical bias estimates, the smallest average RMSE values were obtained for the standardized proportion difference (d_p), the transformed phi coefficient, and the arcsine transformation. Notable also in Figure 3 is that the biserial-phi coefficient produces extremely large RMSE values in many conditions.

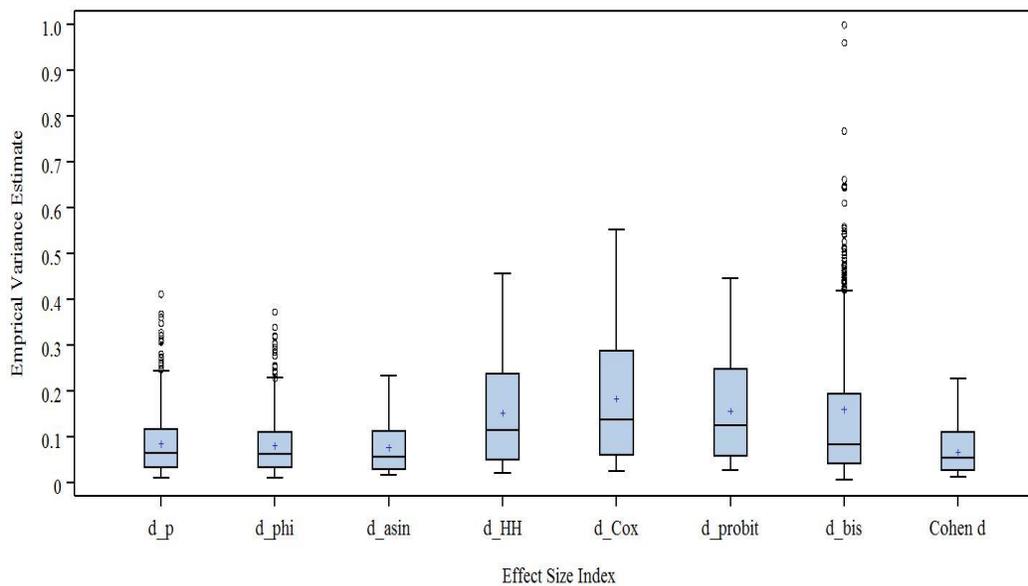


Figure 2. Distributions of Empirical Effect Size Variance Estimates

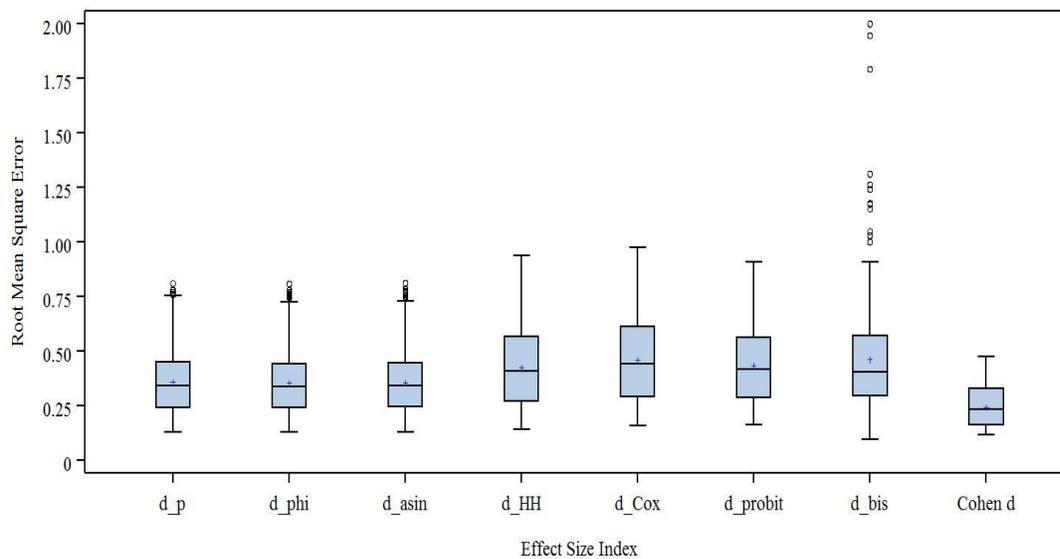


Figure 3. Distributions of RMSE Estimates

CONCLUSIONS

The macro Dichotomized_d provides calculations of the seven effect size indices described above, as well as their sampling variances. These indices have been proposed in the literature as methods to provide the estimated standardized mean difference after continuous data have been dichotomized. As noted in the simulation study conducted by Kromrey and Bell (2012), the statistical bias and sampling error for all seven of these indices compared to those of the effect size obtained prior to dichotomization (Cohen's d), clearly demonstrate tenuous estimations of the effect size parameter after continuous variables have been dichotomized. This was especially problematic with smaller sample sizes and cut points in which the percentages were farther away from the median (e.g. .10 and .70 as opposed to .25 and .40). Working "backwards" to "undo" dichotomized continuous variables is a difficult task. A better choice is for researchers to also report the Cohen's d value prior to the dichotomization. However, if the original data are not available, these indices provide a useful approximation.

The use of the Dichotomized_d macro is very easy; the researcher should simply read data using a regular SAS data step, then call the macro by specifying the data set name, the names of the grouping and outcome variables, the binary values of these two variables and two arguments to indicate the use of weights. The macro output is a simple table that provides details on the sample and the resulting effect size indices. Further, the macro may be easily modified to provide, for example, confidence intervals around the sample effect sizes (i.e., using the point estimates and estimated sampling variances) or to graph the effect size estimates with error bars (i.e., using SAS/GRAPH).

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