SAS and SPSS macros to calculate standardized Cronbach's alpha using the upper bound of the phi coefficient for dichotomous items

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Cronbach's α is widely used in social science research to estimate the internal consistency of reliability of a measurement scale. However, when items are not strictly parallel, the Cronbach's α coefficient provides a lower-bound estimate of true reliability, and this estimate may be further biased downward when items are dichotomous. The estimation of standardized Cronbach's α for a scale with dichotomous items can be improved by using the upper bound of coefficient ϕ. SAS and SPSS macros have been developed in this article to obtain standardized Cronbach's α via this method. The simulation analysis showed that Cronbach's α from upper-bound ϕ might be appropriate for estimating the real reliability when standardized Cronbach's α is problematic.

Reliability of the measures derived from tests and questionnaires refers to the consistency, stability, and repeatability of a data collection instrument (Crocker & Algina, 1986; Cronbach, 1990; Traub, 1994). A reliable instrument will have consistent results if repeated over time or if used by two different investigators. *Internal consistency of reliability* refers to the extent to which all parts of the measurement technique are measuring the same concept. For example, when developing a questionnaire to measure implicit cognition, each question should provide a measure of implicit cognition consistent with the overall results of the test. Although multiple tests are required for estimating stability and equivalence of reliability, only a single test is needed for estimating internal consistency. Cronbach's α coefficient is the most widely used index to estimate the internal consistency of reliability of a scale containing multiple items.

In social science, multiple items are often used in assessments of memory, personality, and other psychological constructs. Under many circumstances, such items are combined (e.g., summed) to form a scale. The scale is then frequently subjected to some form of reliability analysis, and investigators usually report internal consistency in the form of Cronbach's α. For a scale with k items, the standardized Cronbach's coefficient α can be computed from a correlation matrix using the following formula (Cronbach, 1951; Nunnally, 1967):

$$\alpha = \frac{k\bar{r}}{1 + (k-1)\bar{r}}, \qquad (1)$$

where $\bar{r}$ is the mean of the $k \cdot (k-1)/2$ nonredundant correlation coefficients.

The standardized Cronbach's coefficient α is not a lower bound to the true reliability, and it may yield under- or overestimates of the true reliability (Osburn, 2000; Zimmerman, Zumbo, & Lalonde, 1993). Theoretically, when the items of a composite measure are congeneric, τ equivalent, or essentially τ equivalent, standardized α will always exceed the true reliability (Sočan, 2000). However, if the measure contains a small number of heterogeneous items, the standardized Cronbach's α tends to underestimate the true reliability of a measure (Osburn, 2000). And if the items of a scale are characterized by multiple moderately correlated factors, the standardized Cronbach's coefficient α may be seriously underestimated as well. In practice, the standardized Cronbach's α almost always underestimates true reliability (Sočan, 2000).

The underestimation of Cronbach's α is more serious when the items are dichotomous, because correlations among dichotomous items (ϕ coefficients) tend to underestimate true correlations (Brogden, 1946a, 1946b; Gulliksen, 1945). In this article, we propose a method to ameliorate the underestimation of standardized Cronbach's α by incorporating the upper bound of the ϕ coefficient into the calculation of standardized Cronbach's α.

Upper Bound of Correlation Coefficient ϕ

The correlation coefficient ϕ is usually calculated to reflect the relationship between two dichotomous variables. The standardized Cronbach's coefficient α, based on the average correlation among items (see Equation 1), is computed from ϕ when items are dichotomous. A 2×2 frequency table (see Table 1) can be structured for two dichotomous items, X_i and X_j, with "yes" and "no" responses.

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Table 1
A 2 × 2 Table for Dichotomized Items

		X_j		
		Yes	No	Total
X_i	Yes	a	b	a+b
	No	c	d	c+d
	Total	a+c	b+d	N

ϕ can be calculated using the following equation:

$$\phi = \frac{ad - bc}{\sqrt{(a+c)(b+d)(a+b)(c+d)}}. \qquad (2)$$

The upper bound of ϕ between a pair of dichotomous items can be calculated using the following formula (Lord & Novick, 1968; Shrout & Parides, 1992):

$$\phi_{max} = \sqrt{\pi_j \left(1 - \pi_i\right) \big/ \pi_i \left(1 - \pi_j\right)}, \qquad (3)$$

where π_i and π_j are the endorsement ("yes" response) rates of the two items, with $\pi_i \geq \pi_j$.

With the upper bound of ϕ, an estimate of the standardized Cronbach's coefficient α can be obtained directly from Equation 1.

Introduction of SAS and SPSS Macros

As described in this article, an SAS macro has been developed to calculate the standardized Cronbach's coefficient α from the upper bound of ϕ. In this macro, the original Cronbach's coefficient α is obtained from dichotomous items with the SAS procedure PROC CORR. The upper bound of ϕ is calculated from each pair of dichotomous items using Equation 3. The standardized Cronbach's coefficient α is obtained directly from the mean of the upper-bound ϕs.

The SAS macro is provided in Appendix A. In this macro, there are three major input variables defined. One is for the name of the input data set, another is for the string of dichotomous variables, and the third is for the name of the output data set in which the original standardized Cronbach's α and standardized Cronbach's α using upper-bound ϕ will be stored. A data set for testing purposes is attached in Appendix B. An example of SAS codes to run the macro, as well as the SAS output, is provided in Appendix C.

The corresponding SPSS version of our code (syntax and macros) to facilitate calculation of standardized Cronbach's α using upper-bound ϕ was developed also. The code for both the syntax and the macros is provided in Appendix D. The SPSS statements to input the same test data set, the syntax as the SPSS macros run, and the output are attached in Appendix E.

Simulation Analysis

The Alcohol Expectancy Questionnaire is an established instrument used in alcohol studies (e.g., Leigh & Stacy, 1993, 2004; MacKinnon, Nohre, Pentz, & Stacy, 2000). There are 19 items on the alcohol expectancy scale. All items have four categories as potential answers. Positive outcome expectancy items from the scale reported in

Leigh and Stacy (1993) were factor analyzed in a sample of 1,107 adolescents. The three highest-loading items were chosen to form a pseudo-instrument used in the simulation analysis.

The correlations among these three picked items were .75, .57, and .60. Using the correlation matrix, a Monte Carlo study was carried out to determine the percentage of under- or overestimation of the simulated dichotomous items in comparison with the real reliability. First, from the correlation matrix of the three picked items, the continuous data with three variables in normal distribution were simulated. The Cronbach's α from these simulated continuous variables was considered the real reliability (.843). Second, the dichotomous variables were derived from the continuous data with the defined endorsement rates. Then the standardized Cronbach's α and Cronbach's α from upper-bound ϕ were obtained from the dichotomized three items with the SAS macro developed in this study. For each endorsement rate, 100 samples generated, 300 cases in each sample. Table 2 presents the results of this simulation analysis.

This table shows that in the simulated conditions, standardized Cronbach's α seriously underestimated the real reliability, and Cronbach's α from upper-bound ϕ was closer to the true reliability. However, the table also shows that Cronbach's α from upper-bound ϕ was an overly optimistic estimation of reliability (intermediate endorsement rate, 7.8%; high endorsement rate, 0.1%), whereas standardized Cronbach's α underestimated the reliability (intermediate endorsement rate, -17.6%; high endorsement rate, -23.7%). We concluded that Cronbach's α from upper-bound ϕ might be useful in evaluating the reliability of a scale in conditions in which standardized Cronbach's α is problematic. To clearly reveal the relation between true reliability and Cronbach's α from upper-bound ϕ, however, a more extensive simulation study is needed.

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Table 2
Comparison of Standardized Cronbach's α and Cronbach's α
From Upper-Bound ϕ on Simulated Dichotomous Items From
a Pseudo Three-Item Alcohol Expectancy Instrument

	Standardized Cronbach's α			Cronbach's α From Upper-Bound ϕ		
Endorsement Rate[d]	Mean[a]	SD[b]	Percent[c]	Mean[a]	SD[b]	Percent[c]
Low	.641	.044	−23.9	.842	.023	−0.1
Intermediate	.694	.033	−17.6	.908	.013	7.8
High	.643	.044	−23.7	.844	.022	0.1
Low & high	.480	.036	−43.1	.575	.025	−31.8
Low & intermediate	.611	.041	−27.5	.746	.022	−11.4
Intermediate & high	.598	.038	−29.0	.713	.022	−15.4

Note—[a]Mean of standardized Cronbach's α over 100 replications in the simulation analysis. [b]SD of standardized Cronbach's α over 100 replications in the simulation analysis. [c]Percent of Cronbach's α from dichotomous items under-/overestimated on the Cronbach's α from continuous items. The Cronbach's α from simulated continuous data is equal to .843. [d]Endorsement rate in the derived dichotomous items. These rates were as follows: low, .1, .2, .3; intermediate, .4, .5, .6; high, .7, .8, .9; low & high, .1, .2, .9; low & intermediate, .1, .2, .5; intermediate & high, .4, .8, .9.

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APPENDIX A
SAS Macro for Cronbach's Coefficient α From the Upper Bound of Coefficient ϕ

```
/**********************************************************************
 Program: M_UB_Alpha.sas
 Purpose: To Calculate Cronbach's Alpha From Upper Bound of Coefficient Phi
 ------------------------------------------------------------------
 Macro Input Variables:
       indata : data set analyzed
       varlist : a list of dichotomous variables
       outdata: data set with output results
       debug  : for macro developing purposes
 **********************************************************************/

%macro UB_Alpha(indata=, varlist=, outdata=_t, debug=0);

  option nodate nomprint nomlogic pageno=1;
  %if &debug=1 %then %let debug=;
  %else %if &debug^=1 %then %let debug=noprint;

  %ListSep(inString=&varlist, SepCharCode=44, outString=varlist1);
  * we get three strings: &outString _sd1_ _sd2_;
  %do i=1 %to &NV;
    %local _v&i;
    %let _v&i=%scan(&varlist,&i);
    %let _sd_&i=%scan(&_sd1_,&i);
  %end;

  * to calculate alpha from proc corr;
  proc corr data=&indata nomiss alpha cov outp=_alpha;
    var  &varlist;
    title1 "Raw & Standardized Alpha";
```

APPENDIX A (Continued)

```
  title2 "(from Proc Corr)";
run;

* to get the cov & corr matrix;
data _corrout;
* to get the cov & corr matrix;
data _corrout;
 set _alpha;
 if _TYPE_ in ('COV', 'MEAN', 'STD', 'N', 'CORR') then output _corrout;
 if _type_='RAWALPHA' then call symput('RAWALPHA', &_v1);
 if _type_='STDALPHA' then call symput('STDALPHA', &_v1) ;
run;

proc sql noprint;
 select &varlist1 into: &_sd2_
 from _corrout
 where _type_='STD';
quit;

*-- to calculate Cronbach's alpha upper bound  ;
data _null_;
 set _corrout;
 if _type_="MEAN" then do;
  %do i=1 %to &nv;
   _p&i=&&&_v&i;
  %end;

  %do i=1 %to &nv;
   %do j=1 %to &nv;
      %if &i^=&j %then %do;
       if _p&i>=_p&j then do;
        ratio_&i._&j=(_p&j*(1-_p&i))/(_p&i*(1-_p&j));
       end;
       else do;
        ratio_&i._&j=(_p&i*(1-_p&j))/(_p&j*(1-_p&i));
       end;
       phi_up_&i._&j=sqrt(ratio_&i._&j);
       call symput("phi_up_&i._&j",phi_up_&i._&j);
      %end;
    %end;
  %end;
 end;
run;

data _corrout2;
 set _corrout;
 if _type_="CORR" then do;
  %do i=1 %to &nv;
   if _name_="&&&_v&i" then do;
      %do j=1 %to &nv;
       %if &i^=&j %then %do;
          &&&_v&j=&&&phi_up_&i._&j;
       %end;
      %end;
    end;
  %end;
 end;

 if _type_="COV" then do;
  %do i=1 %to &nv;
   if _name_="&&&_v&i" then do;
      %do j=1 %to &nv;
       %if &i^=&j %then %do;
          sd1=symget("_sd_&&&_v&i");
```

APPENDIX A (Continued)

```
           sd2=symget("_sd_&&&_v&j");
           &&&_v&j=&&&phi_up_&i._&j*sd1*sd2;
        %end;
      %end;
    end;
  %end;
 end;
run;

 data &outdata(keep= STDALPHA  salpha_up);
  set _corrout2;
  array stot (i) &varlist;

  retain tot sdtot var sdsum;

  if _n_=1 then do;
   tot=0;sdtot=0;var=0;sdsum=0;
  end;

  if _n_<=&NV then do;
   do i=1 to &NV;
    tot=stot+tot;                    *to sum covariance and variance;
    if i=_n_ then var=stot+var;  *to sum variance;
   end;
  end;

  if _n_=(&NV+2) then do;
   do i=1 to &NV;
    sdsum=stot+sdsum;            *to sum &NV standard deviations;
   end;
  end;

  if _n_>(&NV+3) then do;
   do i=1 to &NV;
    sdtot=stot+sdtot;               *to sum all correlation coefficients;
   end;
  end;

  if _n_=((2*&NV)+3) then do;
   scov=sdtot-&NV;                  *standard covariance;
   salpha_up=(&NV*scov)/((&NV-1)*sdtot);     *standard alpha_up;

   STDALPHA=&STDALPHA;
   lable STDALPHA='Standardized Alpha';

   lable salpha_up='Standardized Alpha Upper-bound';
   output;
  end;
run;

 proc print data=&outdata noobs LABEL ;
  format STDALPHA salpha_up 4.3;
  var  STDALPHA salpha_up ;
  title "=============== Standardized Alpha & Its Upper Bound ==============";
 run;

%mend UB_Alpha;

* Macro to get SD strings;
%macro ListSep(inString=, SepCharCode=44, outString=);

 * number of words;
 %global NV &outString _sd1_ _sd2_;  %local SepChar;
```

APPENDIX A (Continued)

```
data _null_; array _a &inString ;
    call symput('NV',left(dim(_a)));
run;

%*put &inString; %let _outString=; %*put &SepChar;
%do i=1 %to &NV;
    %let t=%scan(&inString,&i);
    %if &i=1 %then %do;
        %let &outString=&t;
        %let _sd1_=_sd_&t;
        %let _sd2_=_sd_&t;
    %end;
    %else %if &i>1 %then %do;
        %let SepChar=%sysfunc(byte(&SepCharCode));
        %let &outString=&&&outString &SepChar &t;
        %let _sd1_=&_sd1_  _sd_&t;
        %let _sd2_=&_sd2_ &SepChar : _sd_&t;
    %end;
%end;

%*put &&outString;
%*put &_sd1_;
%*put &_sd2_;
%mend ListSep;
```

APPENDIX B
Sample of SAS Data Set

```
data t;
    input v1 v2 v3;
    datalines;
1          1          1
1          0          0
1          1          0
1          1          1
1          0          1
1          0          1
1          1          1
1          0          0
0          1          0
1          1          1
1          1          1
1          1          0
1          1          1
1          1          1
0          1          0
1          1          1
0          1          0
1          1          1
1          1          1
1          1          1
1          1          0
1          1          1
1          1          1
1          1          1
1          0          1
1          0          0
1          1          1
0          0          0
1          1          1
1          1          1
;
run;
```

APPENDIX C
Sample of Using the SAS Macro and of Its Output

1. Sample of Using the SAS Macro

```
%UB_Alpha(
  indata=t,
  varlist=v1 v2 v3,
  outdata=t1
);
```

2. SAS Output

=============== Standardized Alpha & Its Upper Bound ===============

Standardized Alpha	Standardized Alpha Upper-bound
0.542	0.865

APPENDIX D
SPSS Syntax and Macros for Cronbach's Coefficient α From the Upper Bound of Coefficient ϕ

```
*Note: 1) The name of input data set should be t1.
*       2) All dichotomous variables should be defined as v plus a number, such as v1, v2, v3, etc.
*       3) The global macro, varNumber, should be assigned an integer.
*       4) The folder, c:\temp, exists.

SET PRINTBACK=off MPRINT=off .

DATA LIST LIST /c.
BEGIN DATA
1
END DATA.
save outfile 'c:\temp\c1.sav'.

DEFINE mp(nbvar=!tokens(1))

* macro 1 --------------- .
!do !cnt=1 !to !nbvar
!if (!cnt = 1) !then
write outfile 'c:\temp\temp.sps' /"*to get percent."/"aggregate outfile 'c:\temp\t2.sav'"/" /break =
    const"/!quote(!concat(' /pv',!cnt,'=mean(v',!cnt,')')).
!ifend.
!if (!cnt = !nbvar) !then
write outfile 'c:\temp\temp.sps' /!quote(!concat(' /pv',!cnt,'=mean(v',!cnt,').')).
!ifend.
!if (!cnt <> 1 &  !cnt <> !nbvar) !then
write outfile 'c:\temp\temp.sps' /!quote(!concat(' /pv',!cnt,'=mean(v',!cnt,')')).
!ifend.
!doend
exe.
!ENDDEFINE.

* macro 2 --------------- .
DEFINE upb_phi(var1=!tokens(1)/
        var2=!tokens(1)/
        var3=!tokens(1)).
do if (!var1 gt !var2).
+ compute !var3=sqrt(!var2*(1-!var1)/(!var1*(1-!var2))).
else if (!var1  le !var2).
+ compute !var3=sqrt(!var1*(1-!var2)/(!var2*(1-!var1))).
end if.
!ENDDEFINE.
```

APPENDIX D (Continued)

```
* macro 3 --------------- .
DEFINE upb_phi1(nbvar=!tokens(1))
!let !const1=1.
!do !cnt=1 !to !nbvar
!let !cnt1= !length(!concat(!blanks(!cnt), !blanks(!const1))).
!do !cntt=!cnt1 !to !nbvar

!let !vt1=!concat('pv',!cnt).
!let !vt2=!concat('pv',!cntt).
!let !vt3=!concat('pv',!cnt,'_',!cntt).

write outfile 'c:\temp\temp.sps' /!quote(!concat('upb_phi var1=',!vt1, ' var2=',!vt2,  ' var3=',!vt3,'.')).

!doend
!doend

exe.
!ENDDEFINE.

* macro 4 --------------- .
DEFINE M_alphaUP(nbvar=!tokens(1))
!let !ttt=!concat(' ').
!do !cnt=1 !to !nbvar
!do !cnt1=2 !to !nbvar
!if (!cnt = 1 & !cnt1=2) !then
!let !ttt= !concat('0 ').
!ifend
!if (!cnt < !cnt1 ) !then
!let !ttt= !concat(!ttt,'+pv',!cnt,'_',!cnt1).
!ifend
!doend
!doend
compute totr=!ttt.
compute totn=!nbvar*(!nbvar-1)/2.
compute avgr=totr/totn.

compute salpha_up=!nbvar*avgr/(1+(!nbvar-1)*avgr).
exe.
!ENDDEFINE.

* macro 5 --------------- .
DEFINE Mcorr(nbvar=!tokens(1))

!let !ttt= !concat('v', !nbvar).

reliability variables = v1 to !ttt
  /model=alpha
  /matrix=out ('c:\temp\corr.sav') noprint.

!ENDDEFINE.

* macro 6 --------------- .
DEFINE Msum(nbvar=!tokens(1))

!do !cnt=1 !to !nbvar
!if (!cnt = 1) !then
write outfile 'c:\temp\temp.sps' /"*to get percent."/"aggregate outfile 'c:\temp\t2.sav'"/" /break =
    const"/!quote(!concat(' /sv',!cnt,'=sum(v',!cnt,')')).
!ifend.
!if (!cnt = !nbvar) !then
write outfile 'c:\temp\temp.sps' /!quote(!concat(' /sv',!cnt,'=sum(v',!cnt,').')).
write outfile 'c:\temp\temp.sps' /!quote(!concat(' /n=sum(const).')).
!ifend.
!if (!cnt <> 1 &  !cnt <> !nbvar) !then
```

APPENDIX D (Continued)

```
 write outfile 'c:\temp\temp.sps' /!quote(!concat(' /sv',!cnt,'=sum(v',!cnt,')')).
!ifend.
!doend
exe.
!ENDDEFINE.


* macro 7 -------------- .
DEFINE Malpha(nbvar=!tokens(1))
!let !ttt=!concat('sv1').
!do !cnt=2 !to !nbvar
!let !ttt= !concat(!ttt,'+sv',!cnt).
!doend
compute totr=(!ttt-!nbvar)/2.
compute totn=!nbvar*(!nbvar-1)/2.
compute avgr=totr/totn.

compute salpha=!nbvar*avgr/(1+(!nbvar-1)*avgr).
!ENDDEFINE.

get file 'c:\temp\c1.sav'.
mp nbvar=varnumber.

get file='c:\temp\t1.sav'.
compute const = 1.
execute.
*list.

include 'c:\temp\temp.sps'.
get file 'c:\temp\c1.sav'.

upb_phi1 nbvar=varnumber.

get file 'c:\temp\t2.sav'.
include  'c:\temp\temp.sps'.
save outfile 'c:\temp\salpha_phi.sav'.
*list.

get file 'c:\temp\salpha_phi.sav'.
M_alphaUP nbvar=varnumber.

save outfile 'c:\temp\salpha_phi.sav'
 /keep salpha_up.
*list.

get file 'c:\temp\t1.sav'.
Mcorr nbvar=varnumber.

get file 'c:\temp\corr.sav'.
select if (rowtype_='CORR').
save outfile 'c:\temp\corr1.sav'
 /drop rowtype_ varname_.

get file 'c:\temp\corr1.sav'.
compute const = 1.
execute.
*list.
get file 'c:\temp\c1.sav'.
Msum nbvar=varnumber.

get file 'c:\temp\corr1.sav'.
compute const = 1.
execute.
*list.
```

APPENDIX D (Continued)

```
include 'c:\temp\temp.sps'.
get file 'c:\temp\t2.sav'.

Malpha nbvar=varnumber.

save outfile 'c:\temp\salpha.sav'
 /keep salpha.
*list.

match files file='c:\temp\salpha_phi.sav'
         /file='c:\temp\salpha.sav'.

variable labels
  salpha_up   "Standardized Cronbach's alpha from Upper Bound phi Coefficient"
  salpha         "Standardized Cronbach's alpha".

save outfile 'c:\temp\alpha.sav'.

set header=no printback=no.

formats salpha_up(F5.3) salpha(F5.3).
variable labels
  salpha_up "Cronbach's alpha from UB phi"
  salpha "Standardized Cronbach's alpha".

display labels.
list.

erase file='c:\temp\t2.sav'.
erase file='c:\temp\corr.sav'.
erase file='c:\temp\temp.sps     '.
erase file='c:\temp\salpha_phi.sav'.
erase file='c:\temp\salpha.sav   '.
erase file='c:\temp\corr1.sav    '.
erase file='c:\temp\c1.sav       '.
```

APPENDIX E
Test of SPSS Syntax and Macros

1. Data for Test

```
DATA LIST LIST /v1 v2 v3  .
BEGIN DATA
1       1       1
1       0       0
1       1       0
1       1       1
1       0       1
1       0       1
1       1       1
1       0       0
0       1       0
1       1       1
1       1       1
1       1       0
1       1       1
1       1       1
0       1       0
1       1       1
0       1       0
1       1       1
1       1       1
1       1       1
```

APPENDIX E (Continued)

```
1    1    0
1    1    1
1    1    1
1    1    1
1    0    1
1    0    0
1    1    1
0    0    0
1    1    1
1    1    1

END DATA.
save outfile 'c:\temp\t1.sav'.
* to DEFINE the number of variables.
DEFINE varNumber()
3
!ENDDEFINE.
```

2. Information for Running the Macros

```
* a) The path needs to be changed if necessary.
* b) The syntax and macros in Appendix D need to be saved in mUB_Alpha.sps.
include 'c:\temp\mUB_Alpha.sps'.
```

3. Output

List of variables on the working file

salpha_up (1) Cronbach's alpha from UB phi
salpha (2) Standardized Cronbach's alpha

```
salpha_up   salpha
  .865        .542
```