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Classical Item and Test Analysis with Graphics: the ViSta-CITA program

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ABSTRACT

Current advances in test development theory are mostly influenced by Item Response Theory (IRT). Notwithstanding this, Classical Test Theory (CTT) still plays a major part in the development of tests for applied educational and behavioral research. This paper describes ViSta-CITA, a computer program that implements a set of classical item and test analysis methods which incorporate innovative graphics whose aim is to provide a deeper insight of analysis results. Such an aim is achieved through the SpreadPlot, a graphical method designed to display multiple, simultaneous, interactive views of the analysis results. It behaves on a dynamic basis, so that users' changes (e.g., selecting a subset of items) are automatically updated in the graphical windows showing the analysis results. Moreover, ViSta-CITA is freely available, and its code is open to modifications or additions by the user. Features like those constitute useful tools for research and teaching purposes related to test development.

Key words: classical test theory, item analysis, dynamic graphics, computer software

Classical Item and Test Analysis with Graphics: the ViSta-CITA program

Graphical techniques play an important role in exploring and modelling statistical data (Wainer & Velleman, 2001; Wilkinson, 1994, 2001; Yu & Behrens, 1995; Yu & Stockford, 2003). When they are well designed, graphics can support "a broad range of user tasks and abilities, are easy to learn, and provide powerful and flexible output formatting" (Colet & Aaronson, 1995). This is especially true for modern dynamic and interactive graphics, which are widely implemented in software like DataDesk or ViSta (Young, Valero-Mora & Friendly, 2006).

The way in which dynamic and highly interactive graphics could be developed and structured in a complex visualization using the powerful XLispStat language and the ViSta Statistical System was discussed in a previous paper (Ledesma, Molina & Young, 2005). Along these lines, this paper presents a computer program, *ViSta-CITA* (Classical Item and Test Analysis with ViSta) oriented toward the analysis of some classical metric characteristics associated with test development. Thus the program integrates a set of analysis methods rooted in Classical Test Theory (CTT), a theoretical framework in test development that has served measurement specialists well for a long time. Even though modern test construction is more influenced by Item Response Theory (IRT), CTT still plays an important part today due to its historical value and simplicity. Besides, it is common practice to teach CTT in graduate and undergraduate courses on measurement and research methods. Another important reason why CTT is widely applied in practice is that it requires smaller samples to estimate the associated item parameters if compared to IRT.

Needless to say, the purpose herein is not to provide a theoretical description of the CTT methods included in ViSta-CITA as they are well-known and have been

documented in many textbooks (e.g., Crocker & Algina, 1986). It is rather to offer an overview of the program's main features and of how they work. Other supplementary ViSta's modules which can be useful in test development are also briefly covered in this paper (e.g., Parallel Analysis, Homogeneity Analysis, and Bootstrap procedures).

ViSta-CITA: a ViSta plugin for classical item and test analysis

ViSta-CITA was developed with the Lisp-Stat programming language and built as a plugin for the ViSta statistical program (Young, 2006). ViSta, "The Visual Statistics System", is a free-distribution, open statistical program, originally set as a test bed for research and development in statistical visualization (Young & Smith, 1991). Ever since its origins in the early 90's, ViSta has extended its field of application to offer a wide range of statistical methods (ANOVA, Simple and Multivariate Regression, Multidimensional Scaling, and Correspondence Analysis, to name a few) and, more specifically, innovative graphical methods associated with the execution of these analyses along with the visualization of their results (Molina, Ledesma, Valero-Mora & Young, 2005).

Being an open system, ViSta's menu of features constantly increases as users interested in implementing new methods develop and integrate them into ViSta. In this respect, when adding new Lisp-Stat code to existing ViSta code, potential programmers can take advantage of the functions already available in this system, thereby avoiding unnecessary repetition. Moreover, since ViSta version 6.4 creation, the implementation of a program architecture based on plugins (Young, 1996) has favored the integration of new analysis methods into the system. This has allowed interested developers to create their own plugin by just following a few specific rules when writing a code, and then simply placing their program in the ViSta plugins folder so as to have it available in the

ViSta environment (Young, 1996; Ledesma, Molina & Young, 2005). ViSta-CITA is an example of a ViSta plugin, and, in view of the fact that it is an open code development, users familiar with the Lisp-Stat programming language can extend or modify the ViSta-CITA code and either add new test analysis procedures or modify the existing ones to adapt them to specific requirements.

ViSta-CITA can be used to analyze some classical test proprieties (e.g., internal consistence, standard error of measurement, underlying test dimensionality) as well as some item proprieties (e.g., location/difficulty, discriminatory power). The program can also be used to compute several types of test sores, including raw scores, percentage scores, and absolute/normalized *Z* and *T* scores. However, the most distinctive feature of ViSta-CITA is the way in which some of this information is presented, i.e., through the use of spreadplots. A spreadplot is a graphical method designed to reflect multiple, simultaneous views of the results of a statistical analysis (Young, Valero-Mora, Faldowski & Bann, 2003). It consists of a container window including linked list and plot windows. These windows show different aspects of the statistical analysis results in a dynamic way, so that changes by the user in one window result in automatic changes in the other windows linked to it.

It is worth noting that, in practice, item/test analysis often involves advancing through an exploratory, iterative process intended to refine the metric proprieties of the test being built. For instance, it is customary to successively delete items with poor performance for purposes of checking the effect of such deletion on the psychometric properties of the revised test. It is precisely in this step-by-step process that the dynamic and interactive character of spreadplots contribute to improve the quality of the test/item analysis results as well as the user experience with this type of statistical software.

The ViSta-CITA program

The ViSta-CITA module has been integrated into the latest version of ViSta, which is available from the website: http://www.uv.es/visualstats/Book/. The program can also be compiled into the previous 6.4 version of ViSta by running the setup program available at: http://www.mdp.edu.ar/psicologia/vista/vista.htm. After installing this plugin, a new menu entry (Item-Test Analysis) appears in ViSta's Analyze menu.

Preparing the Data for Analysis

ViSta-CITA requires that a dataset be formatted as ViSta data files. This requirement can be accomplished following either of these two options: (1) data may be entered through the ViSta data editor (New Datasheet menu item); or (2) text or excel data files can be imported using the ViSta Import Data menu item. The data must be numeric and complete (no empty cells). Should values in the dataset be missing, ViSta's Impute Missing Data command can be used to achieve any of the processing options of ViSta for this type of data. The dataset may contain variables other than item responses/scores; however, before proceeding with the analysis, the user must select the subset of variables representing the responses/item scores to be analyzed by using the Variable Selector command (Data menu).

Figure 1 depicts a partial view of ViSta with an open data file appropriated for Item-Test Analysis. These data are available at the ViSta's Data folder (JSI-Data.lsp file). The file contains data gathered from a job satisfaction study conducted in a public health institution. The variables correspond to the items of a Job Satisfaction Inventory (JSI) and were rated based on a seven-point scale ranging from strong disagreement to strong agreement. Total scores are computed by adding up the 16 item scores. The

observations correspond to a sample of health professionals from a public hospital in Mar del Plata city, Argentina.

[Insert Figure 1 about here]

Running the Analysis

To proceed with the ViSta-CITA analysis, the Item-Test Analysis command must be selected from the ViSta Analyze menu. A dialog box presenting the analysis options (see Figure 2) appears. The first three options provide summary statistics for item and test scores as well as classical item-test indexes. The fourth, fifth and sixth options, in turn, relate to the internal consistency analysis of the questionnaire; while the focus of the seventh option is on the analysis of dichotomous items, as items in binary format usually require specialized analysis (e.g., discrimination index based on point-biserial correlation, p-values, and inter-item Tetrachoric correlations matrix). Finally, the eighth option provides some Exploratory Factor Analyses (EFA) methods.

[Insert figure 2 about here]

The Item/Test Analysis in the ViSta WorkMap

The WorkMap, the upper-left window in ViSta's Desktop (see figure 1), maps the steps taken by the program user during a data analysis session. This map is built and displayed as the analysis progresses. At first, WorkMap has no content; but, as users advance through their data analysis, icons representing data analysis steps are added to the WorkMap. These icons are also connected to previous icons by lines displaying the flow of data analysis. For example, Figure 3 shows that the data analyst first opened a dataset ('JSI'), then applied an analysis model ('Test'), and finally obtained the analysis

results (‘Test-Res’). This last action is represented by an icon with two smaller icons added, which represent the two output approximations of ViSta, i.e., reports and spreadplots. The three icons below correspond to new datasets created from the analysis model applied to the original data.

[Insert figure 3 about here]

Obtaining Reports and Visualizations

When the user selects any of the analysis options, ViSta produces a specific analysis model for the data file just analyzed, which is represented as a new icon in the ViSta’s Desktop Workmap. The program user can examine an analysis model by utilizing one of the two strategies supported by ViSta: either a *report* or a *visualization* of the corresponding model. Hence eight text-based reports and eight visualizations (SpreadPlots) were developed for the eight item-test analysis options available in ViSta-CITA. By default, ViSta displays the analysis results with either a report, a SpreadPlot, or both depending on the preferences set by the program user through the command Options (Preferences menu).

Just like in many other traditional programs, a ViSta report consists of a list with the analysis results in text format. Users of SPSS, Statistica or SAS may rather begin by analysing the text-based report provided by ViSta, which, in fact, is very similar to that available for commercial statistical software. Such a report can be obtained by selecting the Report Model item from ViSta’s Model menu. Figure 4 provides an example of a ViSta-CITA report, more specifically, the report for the reliability analysis based on the Cronbach’s Alpha model, a type of analysis commonly used to evaluate, refine and set the final version of a test. This report includes: the Cronbach’s Alpha index and the

corresponding 95% confidence interval; the Alpha-based estimates of the standard error of measurement and the standard error of estimation; summary statistics based on the relationship between the items and the total test scores; and some descriptive statistics of each item if the item were separated from the test.

[Insert figure 4 about here]

The visualization of each of the eight analysis options in ViSta-CITA (see figure 2) is possible with a SpreadPlot obtained when the Visualize Model item is selected from the ViSta's Model menu. Figure 5 shows the SpreadPlot corresponding to the second analysis option in Figure 2, i.e., the SpreadPlot oriented to the provision of descriptive information on the test scores. Figure 5 displays some of the main features characterizing any ViSta SpreadPlot. The following information is furnished in the windows contained in this specific SpreadPlot:

(1) A list of variables (upper left window) with the names of all the variables (items in this case) in the dataset. In certain cases, this list can work as a control panel to select subsets of items and compute the analysis once again. If the user selects some of the items in the list and then clicks the 'Update for the selected items' button in the 'Update analysis & graphics' window, the rest of the SpreadPlot windows is updated revealing the information corresponding to the selected items. By default, the SpreadPlot is created for all the items in the dataset.

(2) A list of observations (lower left window) with labels for all the cases in the dataset. This list allows the user to identify the selected cases in the graphical windows of the SpreadPlot; also to select and exclude some of them from the analysis. In this last case,

the analysis is recomputed and the rest of the SpreadPlot windows are redrawn accordingly. By default, the SpreadPlot is created for all the cases in the dataset.
(3) A set of graphical windows with information of interest for the analysis model applied to the data. In the case of the SpreadPlot oriented to describe the subjects' scores in the test (see example in Figure 5), a histogram, a box-dot-diamond plot, and a normal probability plot are included.

[Insert figure 5 about here]

Figures 6 displays a more complex ViSta-CITA SpreadPlot, which aims at visualizing the results related to the reliability analysis based on Cronbach's Alpha. Notice should be paid to the fact that, when the user selects a set of items in the list of variables and then clicks the 'Update for the selected items' button, the plots adapt themselves to the selected items, thereby enabling the program user to compare the reliability of different subsets of items. The horizontal line in the upper left window shows the Alpha value for the test –in fact, for the test items selected in the list of variables-, whereas the curved line shows the way in which this reliability index would increase as the test length increases *n* times, in agreement with the Spearman-Brown prophecy formula. The Alpha if-item-deleted plot (lower right plot) illustrates how this coefficient is affected by each of the test items: the vertical axis represents the Alpha value if the item were deleted from the test; and the horizontal black line the Alpha value for all the items, which can be used as a reference to evaluate how each test item (represented as points) influence the reliability coefficient.

[Insert figure 6 about here]

A third illustration of the SpreadPlots implemented in the ViSta-CITA application is provided in Figure 7. The purpose of this SpreadPlot is to visualize the split-half reliability analysis results. The main pieces in this SpreadPlot are a box-diamond-dot plot displaying the test score distributions of the two test halves (odd v. even items) and a scatterplot showing the relationship between both halves (lower plot windows).

[Insert figure 7 about here]

Creating datasets with the subjects' scores

ViSta-CITA allows users to create a new dataset with the subject's scores calculated on the basis of a number of approximations. This can be achieved through the Create Data menu item available in the Model menu of ViSta. Figure 8 illustrates the dialog box shown when this command is chosen. The options below are then available to create a dataset:

(1) Total scores: it creates a univariate dataset containing the test total scores for all the subjects; total scores are computed as the sum of the item scores.

(2) Normalized *Z* scores: it creates a univariate dataset containing the test total scores expressed as normalized *Z* scores.

(3) Normalized *T* scores: it creates a univariate dataset containing the test total scores expressed as normalized *T* scores (mean = 50; standard deviation = 10).

(4) Total/*Z*/*T* scores if item deleted: each one of these options creates a multivariate dataset with the test total scores if items are deleted one by one. This may be useful to compare test scores based on the different k-1 subsets of items.

(5) Mean scores: it creates a univariate dataset containing the mean test scores (test total score divided by the number of items).

(6) Deviation scores: it creates a univariate dataset containing deviation scores from the test mean score.

(7) Estimated test scores: it creates, by default, a univariate dataset containing the estimated scores given the test mean, the standard deviation and the Alpha reliability coefficient. A ViSta-CITA user can modify these parameters by using the dialog box that appears when this option is selected.

(8) Confidence interval for the observed scores: it creates a bivariate dataset with the upper and lower limits of the confidence interval (α=0.05, by default) for the test total scores.

(9) Confidence interval for the estimated scores: it creates a bivariate dataset with the upper and lower limits of the confidence interval (α=0.05, by default) for the estimated test scores, given the computed standard deviation and the value of the reliability coefficient. These parameters can be modified by using the dialog box appearing when this option is selected.

(10) N-tiles = 2: it creates a new univariate dataset with ones for the scores less than the median and twos for the scores equal to or greater than the median.

(11) N-tiles=4: same as the previous option, though now taking the quartiles as the reference values to split the test scores.

[Insert figure 8 about here]

Additional ViSta plugins with application to test development

ViSta-CITA integrates some additional procedures that can be of use in data analysis related to test development. This is the case of the following three plugins: (1) ViSta-PARAN (Ledesma & Valero-Mora, 2007) which supports the application of Parallel Analysis, a method that has been recommended to determine the number of factors to

retain in the application of EFA (Yu, Osborn-Popp, DiGangi & Jannasch-Pennell, 2007; Zwick & Velicer, 1986); (2) ViSta-Homals (Ledesma, Valero-Mora & Young, 2002) which supports the application of Homogeneity Analysis (Gifi, 1990), an optimal scaling data reduction method that can turn useful in the dimensionality analysis of categorical item response data, a type of data not unusual in the psychological context; and (3) ViSta-Boot, ViSta-Coor-Boot and ViSta-Alpha-CI (Ledesma, 2008) which implement some non-parametric bootstrap methods to estimate confidence intervals. Some of them can be applied directly to item analysis. ViSta-Alpha-CI, for instance, computes confidence intervals for the Cronbach's Alpha coefficient. Considering that its application is also supported through dynamic, interactive SpreadPlots, these bootstrap plugins could also be used to introduce students in the data resampling methods.

Discussion

When compared to other statistical programs incorporating CTT techniques (e.g., SPSS, Statistica, SAS), ViSta-CITA offers some advantages over them in the education arena. First, ViSta-CITA is free, non-commercial and available on-line with no restrictions, so students and teachers can easily obtain it through an Internet connection. Second, the program incorporates advanced dynamic graphics (e.g., SpreadPlots) intended to provide a better understanding of the concepts associated with item and test analysis. Thus, ea ch of the eight SpreadPlots implemented in the ViSta-CITA plugin consists of a set of linked, interactive plots programmed to support a specific type of item/test analysis.

The SpreadPlots provides greater dynamism to the analysis thanks to the possibility of graphic interaction with the data and the statistical results. In effect, through the SpreadPlots, the analyst can establish a more fluid "conversation" with the data, favoured by the interactive graphic representations involved. This interactive communication with the graphics allows students and novice analysts to better explore the data, and to more clearly the significance of the statistical information and the theoretical concepts involved. Additionally, ViSta-CITA is developed with the LispStat programming language and runs as a plugin for ViSta (Young, 2006), an open software development environment geared to statistical visualization and data analysis. As a consequence, advanced users can extend or change the program code to better adapt it to their requirements.

A limitation of ViSta-CITA though is that it only includes analysis procedures based on CTT. It does not support certain analysis methods associated with more recent measurement approaches such as the Rasch modeling and other models related to IRT. Indeed this opens a new line of work and a platform for future research. However, as a counterweight to this shortcoming, ViSta-CITA is integrated in a statistical system, ViSta, that already includes a number of analysis methods that can also be useful in test development, such as the Multidimensional Scaling and the Optimal Scaling, among others. A description of the application of these and other methods in ViSta can be found in Young et al., (2006). Planned developments of ViSta-CITA include EFA for ordinal item response data, given that, at present, the EFA option is capable of computing and analyzing Pearson's product-moment and Tetrachoric correlation matrices.

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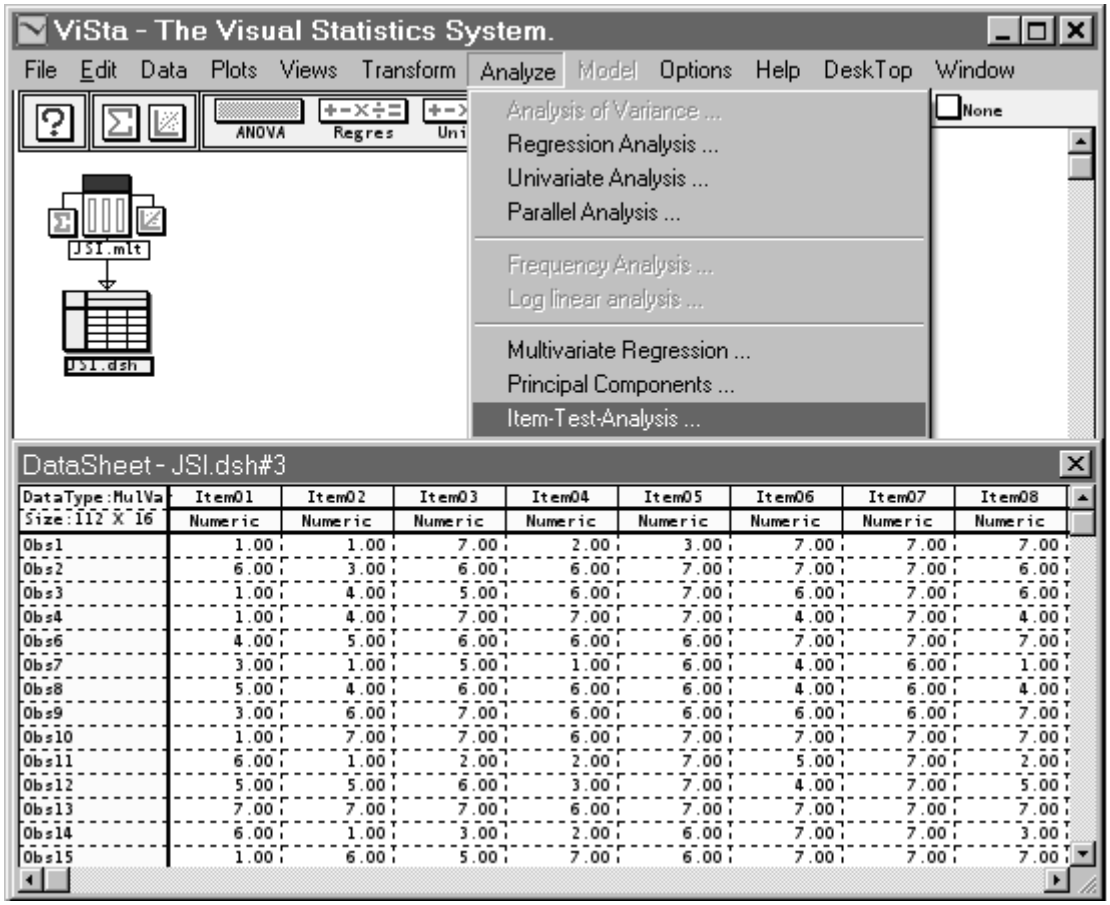
List of Figure Captions

Figure 1



DataType:MulVa	Item01	Item02	Item03	Item04	Item05	Item06	Item07	Item08
Size:112 X 16	Numeric	Numeric	Numeric	Numeric	Numeric	Numeric	Numeric	Numeric
Obs1	1.00	1.00	7.00	2.00	3.00	7.00	7.00	7.00
Obs2	6.00	3.00	6.00	6.00	7.00	7.00	7.00	6.00
Obs3	1.00	4.00	5.00	6.00	7.00	6.00	7.00	6.00
Obs4	1.00	4.00	7.00	7.00	7.00	4.00	7.00	4.00
Obs6	4.00	5.00	6.00	6.00	6.00	7.00	7.00	7.00
Obs7	3.00	1.00	5.00	1.00	6.00	4.00	6.00	1.00
Obs8	5.00	4.00	6.00	6.00	6.00	4.00	6.00	4.00
Obs9	3.00	6.00	7.00	6.00	6.00	6.00	6.00	7.00
Obs10	1.00	7.00	7.00	6.00	7.00	7.00	7.00	7.00
Obs11	6.00	1.00	2.00	2.00	7.00	5.00	7.00	2.00
Obs12	5.00	5.00	6.00	3.00	7.00	4.00	7.00	5.00
Obs13	7.00	7.00	7.00	6.00	7.00	7.00	7.00	7.00
Obs14	6.00	1.00	3.00	2.00	6.00	7.00	7.00	3.00
Obs15	1.00	6.00	5.00	7.00	6.00	7.00	7.00	7.00

Figure 2

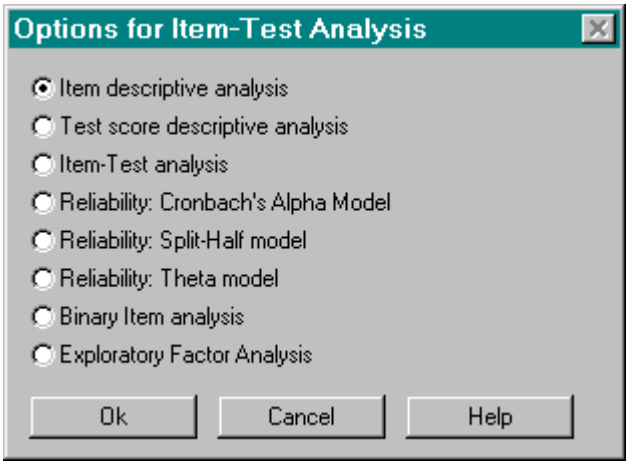
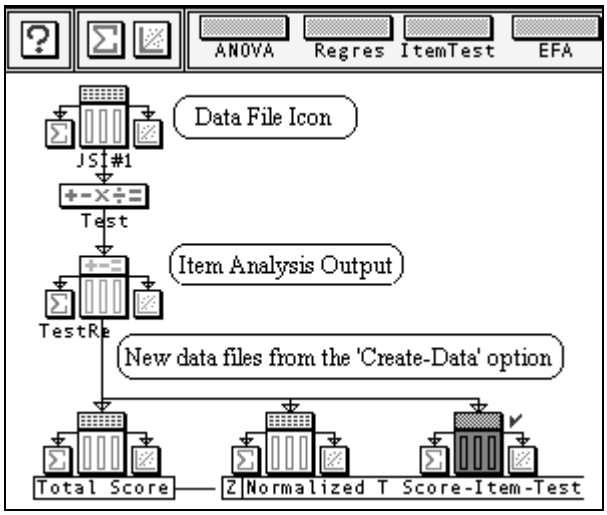

Options for Item-Test Analysis
Item descriptive analysis
Test score descriptive analysis
Item-Test analysis
Reliability: Cronbach's Alpha Model
Reliability: Split-Half model
Reliability: Theta model
Binary Item analysis
Exploratory Factor Analysis
Ok
Cancel
Help

Figure 3


ANOVA
Regres
ItemTest
EFA
Data File Icon
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Test
Item Analysis Output
TestRe
New data files from the 'Create-Data' option
Total Score
Z Normalized T Score-Item-Test

Figure 4

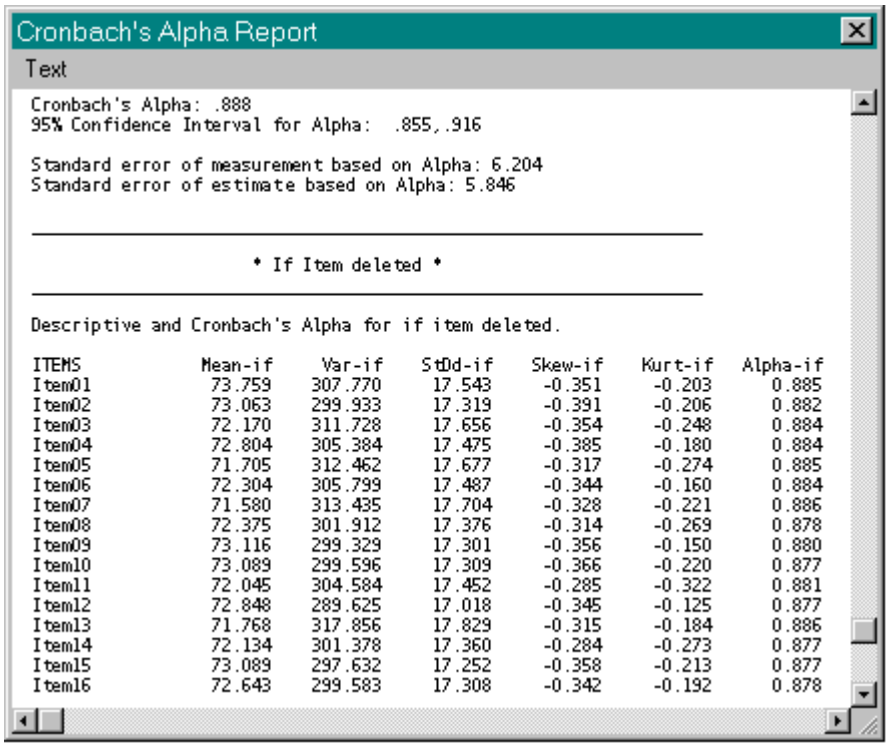

Cronbach's Alpha Report
Text
Cronbach's Alpha: .888
95% Confidence Interval for Alpha: .855,.916
Standard error of measurement based on Alpha: 6.204
Standard error of estimate based on Alpha: 5.846
* If Item deleted *
Descriptive and Cronbach's Alpha for if item deleted.
ITEMS Mean-if Var-if StDd-if Skew-if Kurt-if Alpha-if
Item01 73.759 307.770 17.543 -0.351 -0.203 0.885
Item02 73.063 299.933 17.319 -0.391 -0.206 0.882
Item03 72.170 311.728 17.656 -0.354 -0.248 0.884
Item04 72.804 305.384 17.475 -0.385 -0.180 0.884
Item05 71.705 312.462 17.677 -0.317 -0.274 0.885
Item06 72.304 305.799 17.487 -0.344 -0.160 0.884
Item07 71.580 313.435 17.704 -0.328 -0.221 0.886
Item08 72.375 301.912 17.376 -0.314 -0.269 0.878
Item09 73.116 299.329 17.301 -0.356 -0.150 0.880
Item10 73.089 299.596 17.309 -0.366 -0.220 0.877
Item11 72.045 304.584 17.452 -0.285 -0.322 0.881
Item12 72.848 289.625 17.018 -0.345 -0.125 0.877
Item13 71.768 317.856 17.829 -0.315 -0.184 0.886
Item14 72.134 301.378 17.360 -0.284 -0.273 0.877
Item15 73.089 297.632 17.252 -0.358 -0.213 0.877
Item16 72.643 299.583 17.308 -0.342 -0.192 0.878

Figure 5

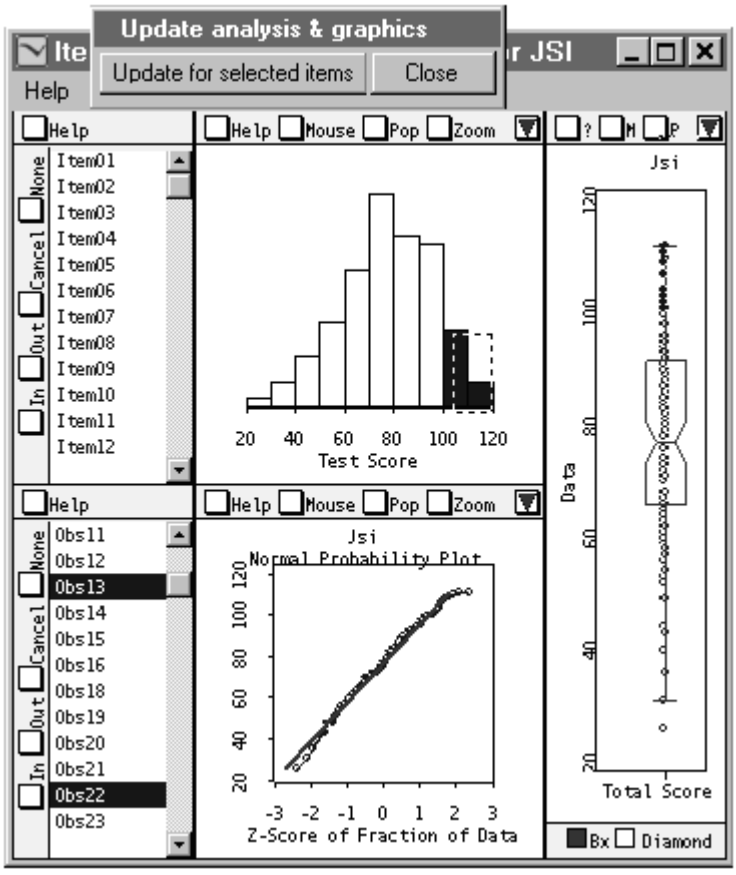

Update analysis & graphics
Update for selected items
Close
Help
Help
Item01
Item02
Item03
Item04
Item05
Item06
Item07
Item08
Item09
Item10
Item11
Item12
None
Cancel
Out
In
Help Mouse Pop Zoom
20 40 60 80 100 120
Test Score
Help
Obs11
Obs12
Obs13
Obs14
Obs15
Obs16
Obs18
Obs19
Obs20
Obs21
Obs22
Obs23
Jsi
Normal Probability Plot
20 40 60 80 100 120
-3 -2 -1 0 1 2 3
Z-Score of Fraction of Data
Jsi
Data
20 40 60 80 100 120
Total Score
Bx Diamond

Figure 6

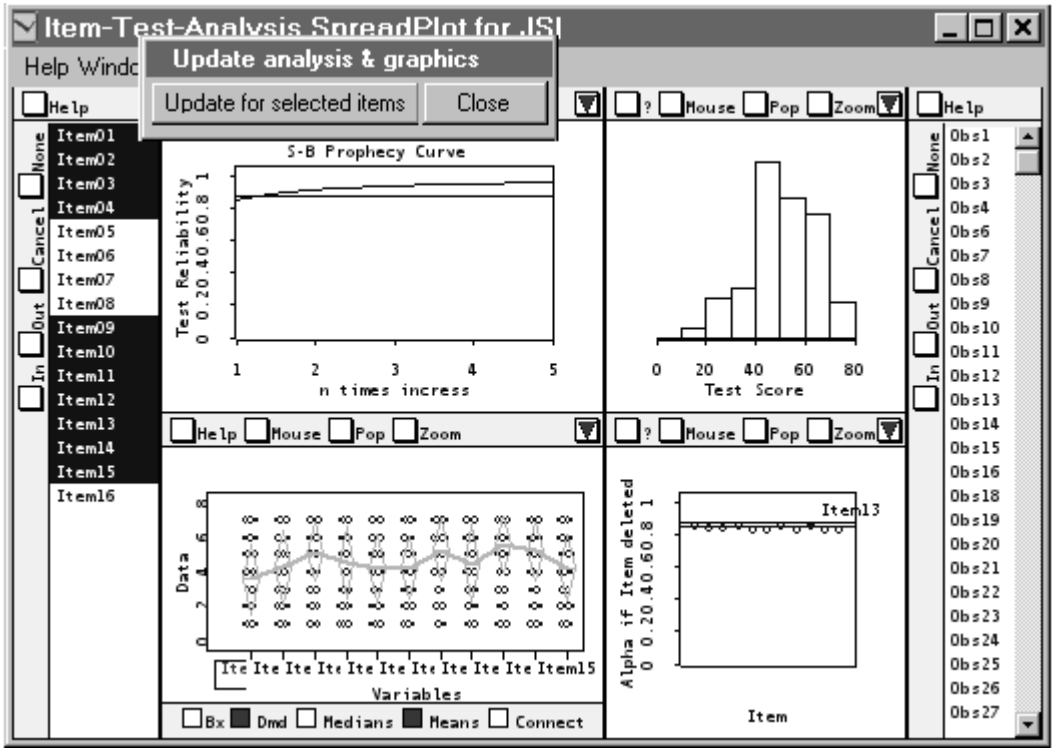

Item-Test-Analysis SpreadPlot for JSL
Help Windc
Update analysis & graphics
Update for selected items
Close
Help
Item01
Item02
Item03
Item04
Item05
Item06
Item07
Item08
Item09
Item10
Item11
Item12
Item13
Item14
Item15
Item16
None
Cancel
Out
In
S-B Prophecy Curve
Test Reliability
0 0.20.40.60.8 1
1 2 3 4 5
n times incress
? Mouse Pop Zoom
0 20 40 60 80
Test Score
Help
Obs1
Obs2
Obs3
Obs4
Obs6
Obs7
Obs8
Obs9
Obs10
Obs11
Obs12
Obs13
Obs14
Obs15
Obs16
Obs18
Obs19
Obs20
Obs21
Obs22
Obs23
Obs24
Obs25
Obs26
Obs27
Help Mouse Pop Zoom
Data
0 2 4 6 8
Item15
Variables
Bx Dmd Medians Means Connect
? Mouse Pop Zoom
Alpha if Item deleted
0 0.20.40.60.8 1
Item13
Item

Figure 7

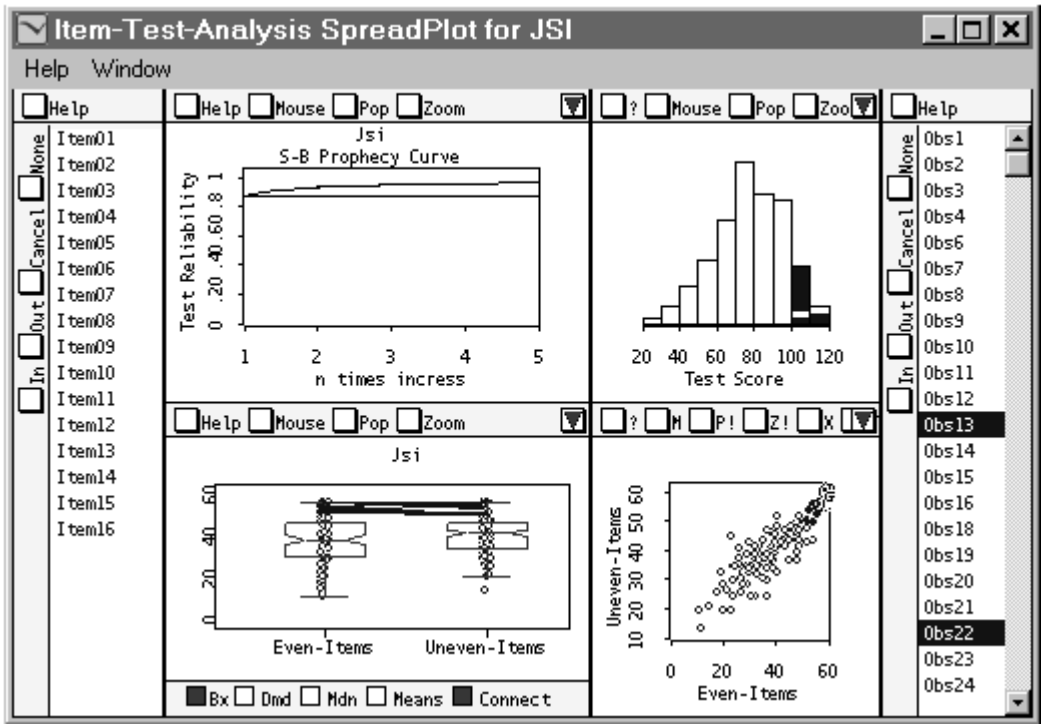
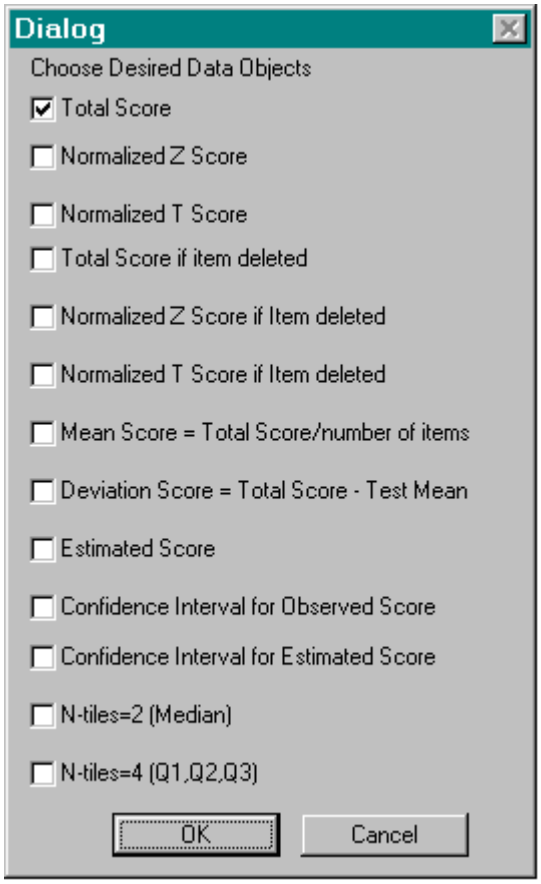

Item-Test-Analysis SpreadPlot for JSI
Help Window
Help
Item01
Item02
Item03
Item04
Item05
Item06
Item07
Item08
Item09
Item10
Item11
Item12
Item13
Item14
Item15
Item16
None
Cancel
Out
In
Help Mouse Pop Zoom
Jsi
S-B Prophecy Curve
Test Reliability
0 .20 .40 .60 .8 1
1 2 3 4 5
n times incress
? Mouse Pop Zoo
20 40 60 80 100 120
Test Score
Help
Obs1
Obs2
Obs3
Obs4
Obs6
Obs7
Obs8
Obs9
Obs10
Obs11
Obs12
Obs13
Obs14
Obs15
Obs16
Obs18
Obs19
Obs20
Obs21
Obs22
Obs23
Obs24
Help Mouse Pop Zoom
Jsi
0 20 40 60
Even-Items
Uneven-Items
Bx Dmd Mdn Means Connect
? M P! Z! X
Uneven-Items
10 20 30 40 50 60
0 20 40 60
Even-Items

Figure 8


Dialog
Choose Desired Data Objects
Total Score
Normalized Z Score
Normalized T Score
Total Score if item deleted
Normalized Z Score if Item deleted
Normalized T Score if Item deleted
Mean Score = Total Score/number of items
Deviation Score = Total Score - Test Mean
Estimated Score
Confidence Interval for Observed Score
Confidence Interval for Estimated Score
N-tiles=2 (Median)
N-tiles=4 (Q1,Q2,Q3)
OK
Cancel