Doing Statistics with WinStat

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Dedicated to Margarita

This manual was generated using LaTeX. The WinStat software (binary only) together with this manual (as PDF) are available at: http://www.intergate.com/~harald/HemoLab.html. The author would appreciate receiving **picture postcards** from the home town of people who use this software. As always, bug reports or suggestions for improvements are also highly appreciated.

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Chapter 1

Legal Issues

1.1 Free for non commercial use - Licence

The WinStat software is **free for non commercial use**. WinStat can be used for free by a party if the goal does not involve commercial gain. If it is used for commercial gain, a commercial licence is required. Please contact the author of the software and copyright holder (Harald M. Stauss) if a commercial licence is required. If WinStat is used for charity/personal objectives a commercial licence is still required, but payment for the commmercial licence may be waived.

1.2 No Warranty

THERE IS NO WARRANTY FOR THE WINSTAT SOFTWARE, TO THE EXTENT PERMITTED BY APPLICABLE LAW. EXCEPT WHEN OTHERWISE STATED IN WRITING THE COPYRIGHT HOLDERS AND/OR OTHER PARTIES PROVIDE THE PROGRAM "AS IS" WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THE ENTIRE RISK AS TO THE QUALITY AND PERFORMANCE OF THE SOFTWARE IS WITH YOU. SHOULD THE SOFTWARE PROVE DEFECTIVE, YOU ASSUME THE COST OF ALL NECESSARY SERVICING, REPAIR OR CORRECTION.

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Chapter 2

Introduction

This manual describes the WinStat software. WinStat is a MS-Windows program that is designed to analyze experimental data with commonly used statistical procedures. The algorithms are based on several sources, including books on statistics [2, 4, 7, 10], computer programming [3, 8, 11], and freely available algorithms [9]. I felt that it was necessary to develop such a software, because there is currently no statistical analysis software available for MS-Windows that meet the following criteria:

1. freely available at no cost for non commercial use
2. easy to use
3. powerful statistical functions
4. concise and clearly structured print outs of the results
5. documentation available

As far as criteria one is concerned, there exist some freely available statistical analysis software for MS-Windows (e.g., The R Project, AM Statistical Software, Dataplot, OpenStat, Fiasco/PSPP) and it is well worth to check them out. However, I found that most of the freely available statistics packages are either difficult to use, do not offer important statistical tests, such as "post-hoc tests for ANOVAs" or "2-way ANOVAs", or the print outs of the results were relatively difficult to read or consisted of several pages of more or less useful information. The large statistical packages (SAS, SPSS, SYSTAT) that offer nearly unlimited statistical functions are not freely available. Thus, I have started to develope this software according to the criteria mentioned above.

In order to make this software a success, I need feedback. Any suggestions to improve WinStat are highly appreciated.

Chapter 3

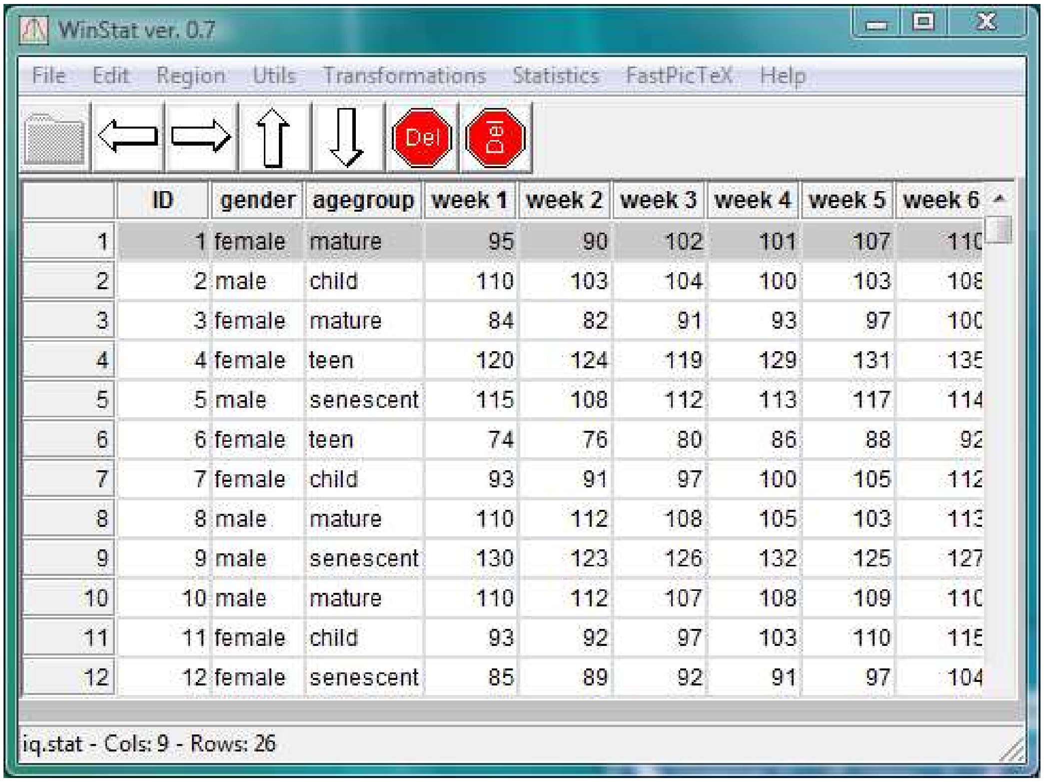
Installation

The statistics package WinStat is a MS-Windows program currently included with the HemoLab software. Installation is done using the installer for the HemoLab software that can be obtained from:
http://www.intergate.com/~harald/HemoLab.html.

You will find the WinStat software in your Windows Start Menu (lower left corner of screen) under “All Programs”, subfolder “HemoLab”.

This subfoder also includes a link to Uninstall all components of HemoLab, including WinStat. Before installing a new version of HemoLab, please make sure you uninstall any previoulsy installed version of HemoLab using the included Uninstall software.

After installation of the HemoLab software, you should be able to start the WinStat software and see the WinStat main window as shown in Fig. 3.1.



	ID	gender	agegroup	week 1	week 2	week 3	week 4	week 5	week 6
1	1	female	mature	95	90	102	101	107	110
2	2	male	child	110	103	104	100	103	108
3	3	female	mature	84	82	91	93	97	100
4	4	female	teen	120	124	119	129	131	135
5	5	male	senescent	115	108	112	113	117	114
6	6	female	teen	74	76	80	86	88	92
7	7	female	child	93	91	97	100	105	112
8	8	male	mature	110	112	108	105	103	113
9	9	male	senescent	130	123	126	132	125	127
10	10	male	mature	110	112	107	108	109	110
11	11	female	child	93	92	97	103	110	115
12	12	female	senescent	85	89	92	91	97	104

iq.stat - Cols: 9 - Rows: 26

Figure 3.1: Main Window of WinStat

Chapter 4

File Commands

The commands in the File menu (see Fig. 4.1) allow to handle the data files for use with WinStat. Two file formats are supported. The ASCII format to import and export data in a format that can be read by nearly every other program. In addition, a special WinStat format is also supported. Files saved in this format include information on the variable names and other parameters.

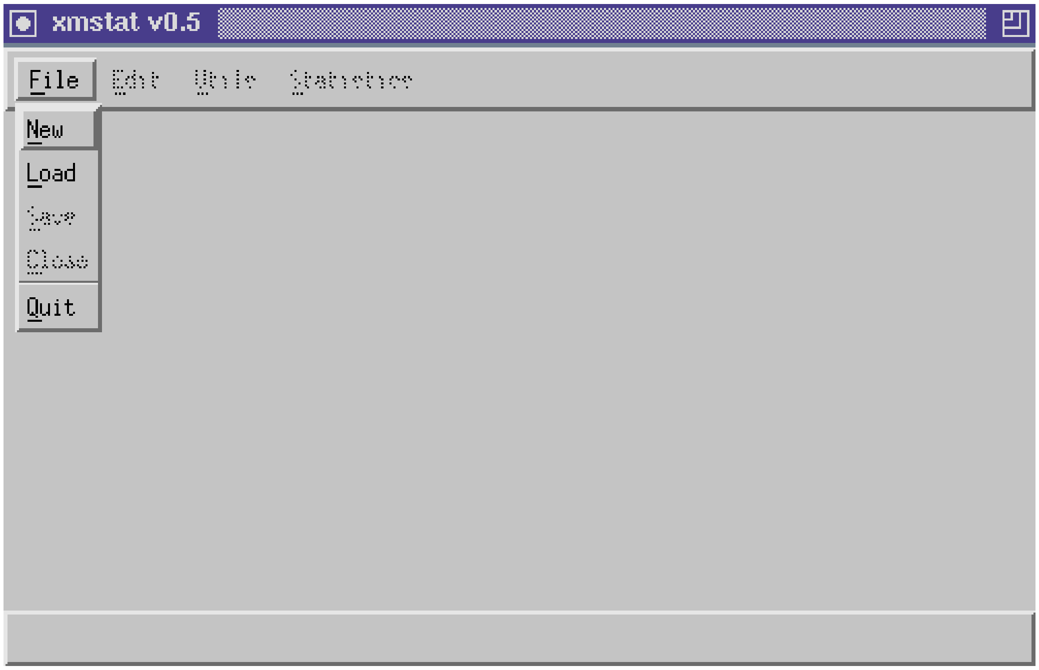


Figure 4.1: Commands in the File menu

4.1 Arrangement of data for WinStat

Arrangement of data will be explained by a simple example. Suppose you want to perform statistics on the question whether women and men of different age differ in their intelligent quotients (IQ) and whether the test persons will obtain better IQ-scores if the tests are repeated once every week for a time period of six weeks. Suppose we have 26 test persons (14 female and 12 male). The database of this study consists of 156 IQ-values (26*6). How should these values be arranged for use with WinStat? In general, data are arranged in rows and colums. Observations (IQ-values from each test person) are arranged in rows, while variables (IQ values of all persons on a specific week) are arranged in columns. The data of this example are shown in Table 4.1 and are provided in the files “iq.ascii” and “iq.stat” in the examples directory. In addition, there may be variables that do not consist of experimental data. Such variables (columns) contain information as to whether an observation (a person) belongs to a specific group (goup of women or men, agegroup).

The data in Table 4.1 are not from a real experiment. They are all fabricated and fictuous and should only serve as example for WinStat.

4.2 New

This menu item can be used to enter new data sets from the keyboard. Let us assume we want to enter the data from Table 4.1. These data consist of 26 observations (subjects or persons) and 9 variables (6 IQ-values and one variable for the ID-number of the person, one for the gender, and another variable for the agegroup). Thus, in the dialog that appears (see Fig. 4.2) we enter a number of 26 rows and 9 columns before we hit the OK-button. Now a spreadsheet apears with cells for 9 variables and 26 observations (see Fig. 4.3). We can use the scrollbars to scroll through the spreadsheet. It is possible to change the width of the columns by pressing the shift-key and simultaneously dragging the mouse with the 2^{nd} mouse button pressed. In order to follow the example, we could now enter the data from Table 4.1.

4.3 Load

If we don’t want to enter all 156 data values manually, we can use the menu-item LOAD from the FILE menu and load the data from the file “iq.stat” or “iq.ascii” from the examples directory. As mentioned above, WinStat can read ASCII files and special WinStat files. The LOAD DATA dialog (see

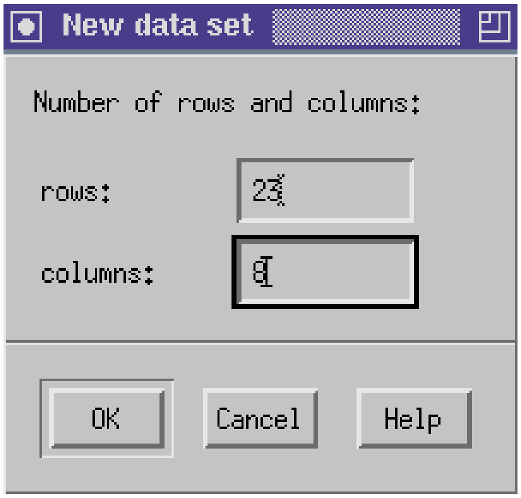
Table 4.1: IQ values from women and men of different age on six successive tests, each one week apart.

ID	gender	agegroup	week 1	week 2	week 3	week 4	week 5	week 6
1	female	mature	95	90	102	101	107	110
2	male	child	110	103	104	100	103	108
3	female	mature	84	82	91	93	97	100
4	female	teen	120	124	119	129	131	135
5	male	senescent	115	108	112	113	117	114
6	female	teen	74	76	80	86	88	92
7	female	child	93	91	97	100	105	112
8	male	mature	110	112	108	105	103	113
9	male	senescent	130	123	126	132	125	127
10	male	mature	110	112	107	108	109	110
11	female	child	93	92	97	103	110	115
12	female	senescent	85	89	92	91	97	104
13	female	child	76	79	86	91	87	98
14	male	teen	100	102	95	97	98	99
15	female	mature	98	102	106	111	113	115
16	male	teen	91	89	95	88	87	93
17	female	senescent	77	81	85	89	91	94
18	male	mature	120	105	110	122	117	116
19	male	child	113	106	105	111	107	114
20	female	senescent	90	89	96	99	103	109
21	female	teen	86	88	92	91	97	102
22	male	mature	102	99	105	95	101	97
23	female	mature	76	80	82	87	93	96
24	male	child	80	85	79	75	82	85
25	male	teen	95	97	88	92	94	91
26	female	senescent	85	87	91	93	96	95

Fig. 4.4, left) allows to enter the directory that contains the data files (examples) and to select a file (iq.stat). Don't forget to select also the appropriate file type (i.e. ASCII or STAT) before you hit the OK-button.

4.4 Save

Once we have created a new spreadsheet with the File New command and entered the data that we want to analyse, we may want to save the data. We can do this with the File Save command. The dialog that appears is shown in Fig. 4.4 (right). We need to select the directory in which we want to save the data file, we need to enter a file name and we need to choose a file type. We can choose between the ASCII file format and the WinStat file



Number of rows and columns:

rows: 23

columns: 8

Figure 4.2: New data set dialog

format. The ASCII file format should be chosen if we want to import the data into another program. The WinStat file format should be preferred if we want to reuse the file with the WinStat program. As mentioned earlier, the WinStat file format also saves informations on the variable names along with other information.

If the file already exists, a warning will appear that reminds you that this particular file already exists and the possibilities are offered to overwrite the file or to cancel the save process.

4.5 Close

The File Close command closes the spreadsheet. The data are **not** saved and may be lost if you did not use the File Save command before. Thus, be careful when using this menu item.

4.6 Exit

The File Exit menu item ends the program. If you didn't save the data before clicking on this menu item, your data will be lost. There is no warning that informs you that the data are not saved yet. Thus, think twice before exiting from the WinStat program.

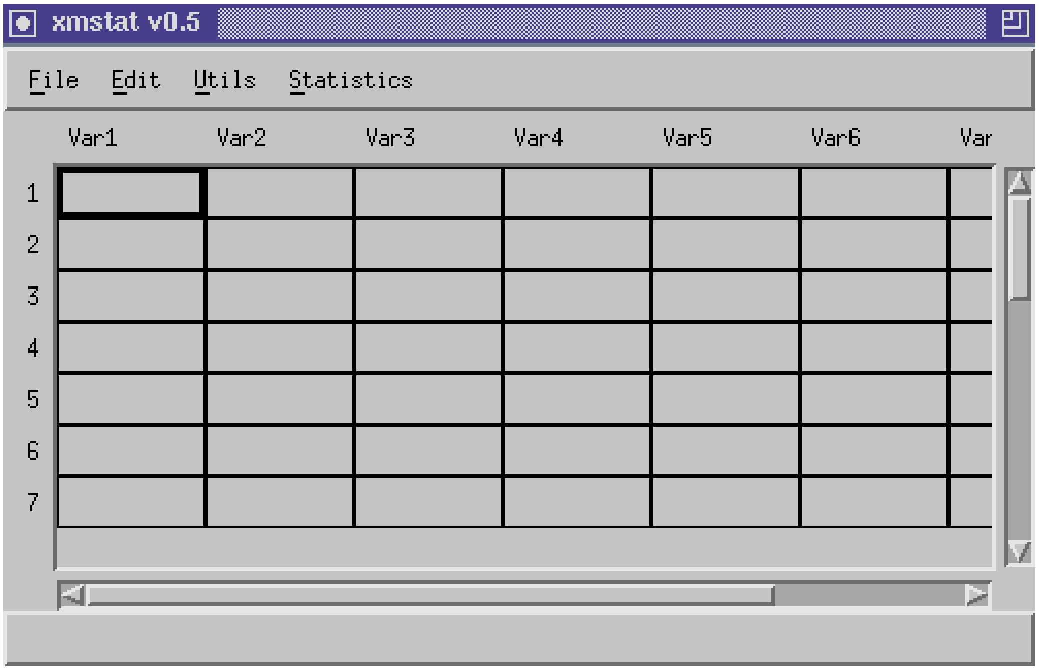
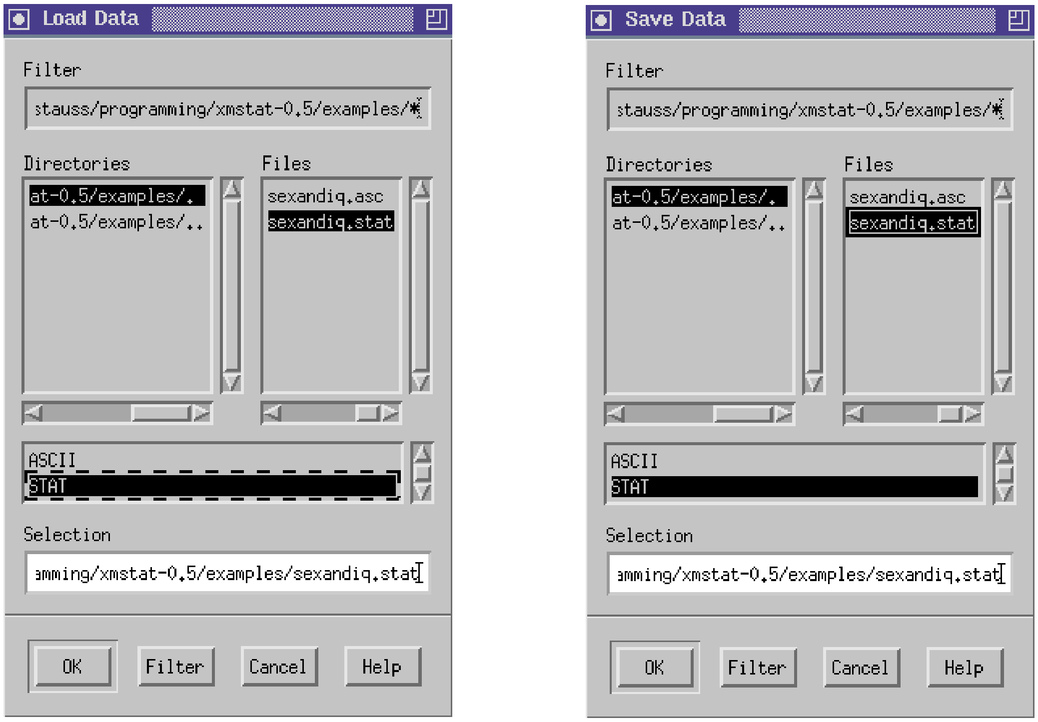


Figure 4.3: Main window after File New with 26 rows and 9 columns



Filter: stauss/programming/xmstat-0.5/examples/*

Directories: at-0.5/examples/. at-0.5/examples/..

Files: sexandiq.asc sexandiq.stat

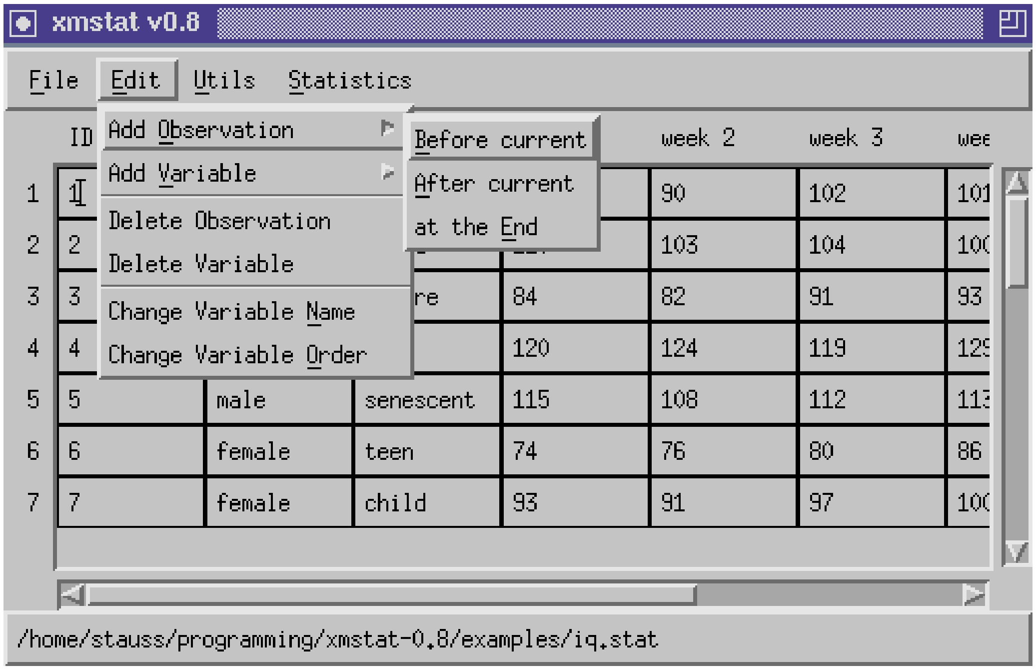
Selection: amming/xmstat-0.5/examples/sexandiq.stat

Figure 4.4: Load Data and Save Data dialogs

Chapter 5

Edit Commands

Once you have entered some data manually or you have loaded a data file, you may want to add additional obsersations or variables. Sometimes it is necessary to delete observations or variables that are found to be unvalid for some reasons. In addition, the names of the variables may be changed from the default variable names that consists of the prefix "VAR" and the number of the variable to more meaningful variable names. All these procedures can be reached from the Edit menu that is shown in Fig. 5.1.



	ID				week 2	week 3	wee
1	1				90	102	101
2	2				103	104	10
3	3		re	84	82	91	93
4	4			120	124	119	12
5	5	male	senescent	115	108	112	11
6	6	female	teen	74	76	80	86
7	7	female	child	93	91	97	10

/home/stauss/programming/xmstat-0.8/examples/iq.stat

Figure 5.1: Commands in the Edit Menu

5.1 Add Observation

This menu item has a submenu (see Fig. 5.1) that allows to add new observations (p.e. new subjects for the “inteligent quotients study”) before the current observation, or after the current observation, or at the end of the spreadsheet (i.e. after the last observation). Since sorting of the spreadsheet must be considered to be garbled after insertion of new observations, the sort variables that may have been defined by the Utils Sort Variable menu are unselected and the database is defined to be unsorted.

5.2 Add Variable

This menu item also has a submenu that allow to add new variables (p.e. IQ-values for a seventh week) before the current variable, or after the current variable, or at the end of the spreadsheet (i.e. after the last variable).

5.3 Copy Observation

This menu item allows to copy the current observation. A copy of the current observation is inserted to the spreadsheet at the position following the current row (observation). After copying observations, the sort variables are unselected and the database is considered to be unsorted.

5.4 Copy Variable

This menu item allows to copy the current variable. A copy of the current variable is inserted to the spreadsheet at the position following the current column (variable). This function is particularly useful, if one-variable transformations should be calculated from a variable, because variables from which one-variable transformations are performed are replaced by the transformation. Thus, it is useful to create a copy of the variable first and then perform the one-variable transformation on the copy of the variable. The variable name of the copy is created based on the original variable name and the suffix “_c”.

5.5 Delete Observation

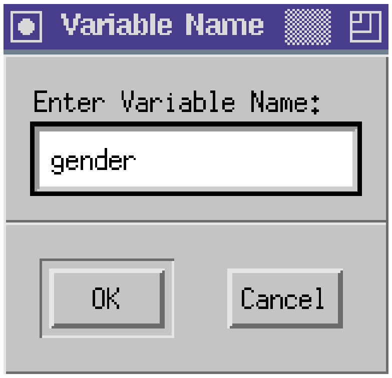
This menu item simply allows to delete the observation at which the cursor is located. At least one observation must remain in the spreadsheet. If you want to delete all observations you may use the File Close menu item.

5.6 Delete Variable

This menu item allows to delete the variable at which the cursor is located. At least one variable must remain. If you want to delete all variables use the File Close menu item.

5.7 Change Variable Name

The Edit menu also allows to change the name of the variable at which the cursor is located. A dialog box (see Fig. 5.2) will pop up that shows the current variable name in a text field. The name can be changed by entering a new name in the text field and clicking on the OK-button. Please note that it is important that all variable names differ from each other.



Enter Variable Name: gender

Figure 5.2: The Variable Name dialog

5.8 Change Variable Order

This menu item pops up a dialog box (see Fig. 5.3) with two lists. One list contains all variable names in the file and the other list ist empty. If you click on a variable name on the left list, the variable will be moved to the list on the right side. By clicking on the variable names you can create a new list of variable names (on the right side) that represents the new order of the variables in the file. The OK-button rearranges the file according to the list on the right side, the Cancel-Button leaves everything as it is. If not all variable names are moved from left to right, the variables in the right list are preceding the variables in the left list.

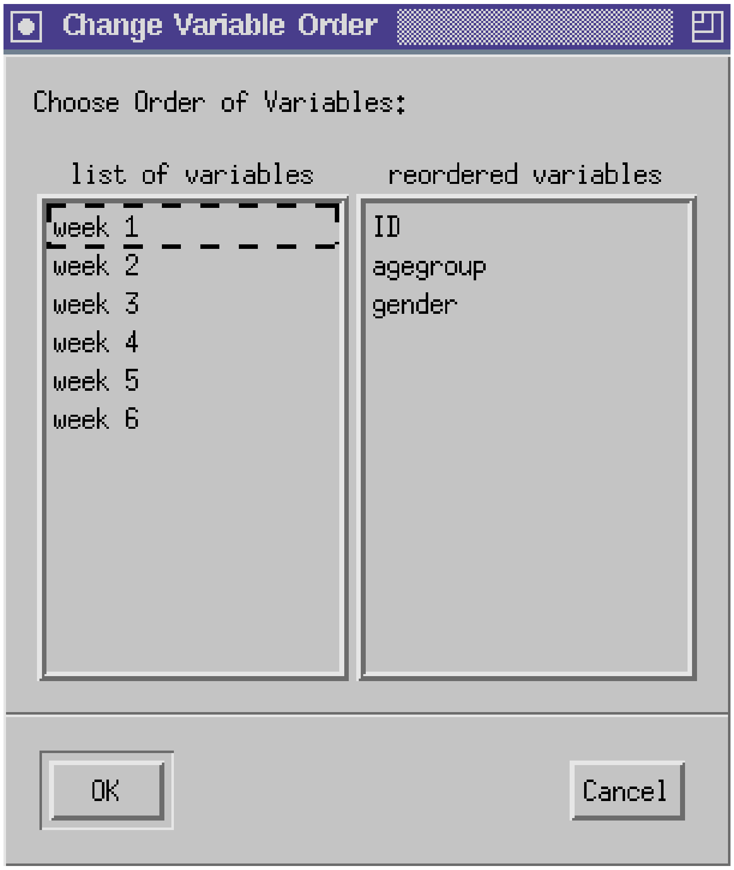


Figure 5.3: The Change Variable Order dialog

Chapter 6

Region Commands

The commands in this menu are operating on the data in a selected rectangle. A rectangular area of cells can be selected by pressing the first mouse button and dragging over the cells that should be included in the marked rectangle. The rectangle must start in a different cell than the currently selected cell, because dragging in the current cell operates on the content of this particular cell. Once a rectangular area of cells is selected, these cells can be cleared by the CUT command, copied into an internal buffer (COPY) and then pasted to a new destination. In addition, the cells in the rectangular area can be transposed, i.e. the rows and columns can be exchanged.

6.1 Cut

This command clears the selected (marked) cells and copies the content in an internal buffer. From this buffer, the cleared cells can be copied into a new destination by the PASTE command.

6.2 Copy

Like the CUT command, this command copies the content of the selected (marked) cells in an internal buffer, but does not clear the selected cells. Again, this buffer can be copied into a new destination by the PASTE command.

6.3 Paste

The paste command allows to copy the content of the internal buffer to a certain position. At the position of the current cell, the upper left corner of the rectangle that had been transfered into the internal buffer by the CUT or COPY command will be located.

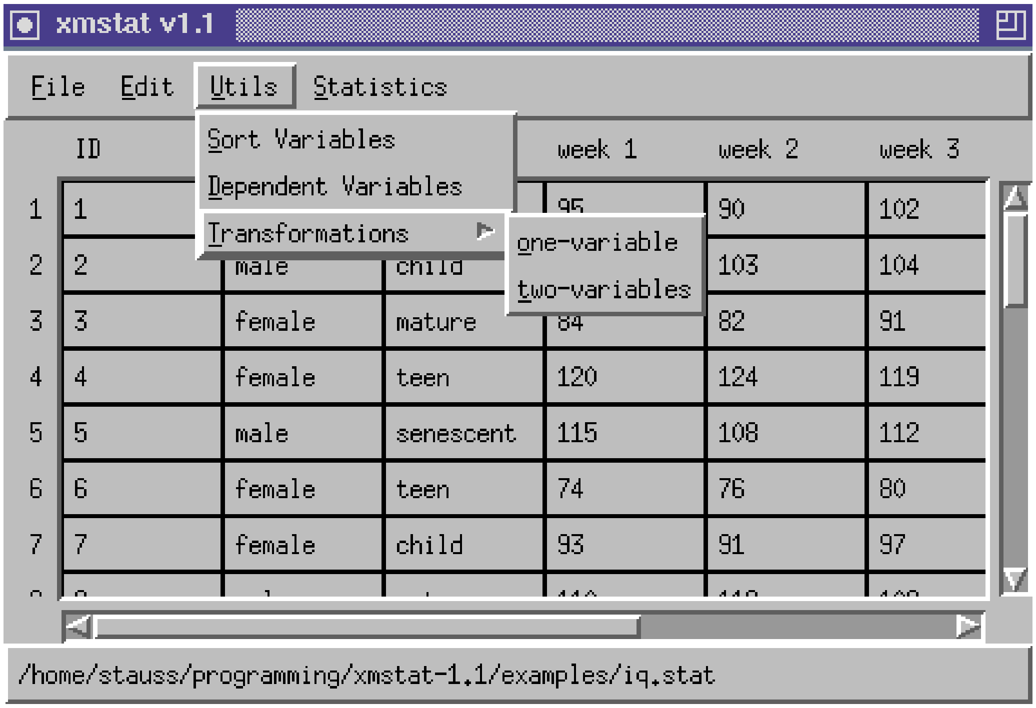
6.4 Transpose

The TRANSPOSE command allows to exchange the rows and columns in the marked rectangle. This rectangle must consist of the same number of rows and columns.

Chapter 7

Utils Commands

The commands in this menu (see Fig. 7.1) are intended to select variables that define subgroups for the calculations and to select the dependent variables from which statistics should be calculated. In addition, transformations can be performed on the values in the variables by the Utils Transformations menu item.



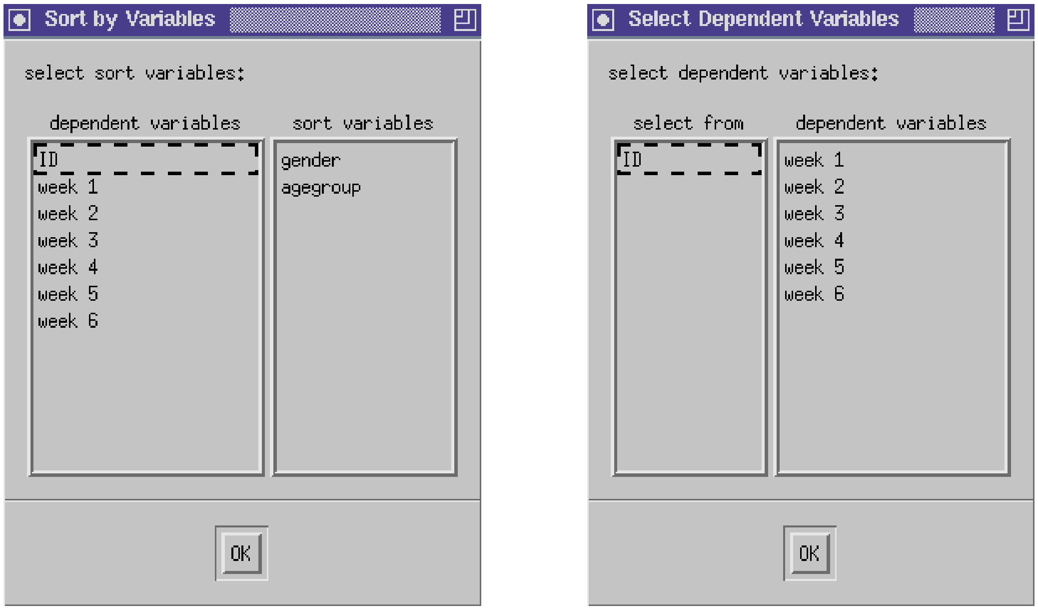
	ID			week 1	week 2	week 3
1	1			95	90	102
2	2	male	child		103	104
3	3	female	mature	84	82	91
4	4	female	teen	120	124	119
5	5	male	senescent	115	108	112
6	6	female	teen	74	76	80
7	7	female	child	93	91	97

/home/stauss/programming/xmstat-1.1/examples/iq.stat

Figure 7.1: Commands in the Utils menu

7.1 Sort Variables

Sort variables are variables that define subgroups of the database. A sort variable can be a column of the spreadsheet that defines certain characteristics of the subjects. In the database for the IQ-values from women and men (see Table 4.1) the sort variable “gender” naturally has two levels, i.e. female and male. The sort variable “agegroup” that defines subgroups based on the age of the subjects has four levels (i.e. child, teen, mature, senescent). To define sort variables just click on the variable name on the left list in the Sort by Variables dialog (see Fig. 7.2). The variable will be moved to the list of sort variables on the right side of the dialog. After clicking on the OK button, the subjects in the spreadsheet will be rearranged according to the sort variables. Fig. 7.3 shows the spreadsheet after sorting by gender and agegroup. Note how the rows of the spreadsheet (observations) are rearranged. First there are all female subjects. The subgoup of females is further sorted by the agegroups. Please also note that the order of the sort variables matter. If you calculate descriptive statistics after selecting the sort variable “gender” you get the results of the descriptive statistics separated for all female and all male subjects of the study. If more than one sort variable are selected, statistics are calculated for as many subgroups as the combination of all selected subgroups allow.



dependent variables: ID, week 1, week 2, week 3, week 4, week 5, week 6
sort variables: gender, agegroup

select from: ID
dependent variables: week 1, week 2, week 3, week 4, week 5, week 6

Figure 7.2: Sort by Variables and Select Dependent Variables dialogs

7.2 Dependent Variables

Dependent variables are the variables (columns) from which statistics will be calculated. You can easily select the dependent variables by clicking on the variable names on the left list of the SELECT DEPENDENT VARIABLES dialog (see Fig. 7.2). The variables will be moved to the list of dependent variables. In the database from Table 4.1 you may want to select the variables for the IQ values from the six weeks as dependent variables while you certainly don't want to calculate any statistics from the ID-numbers of the subjects.

7.3 Transformations

Transformations can be performed on a single variable or on two variables. In the case of single variable transformations, the content of the cells of this variable will be overwritten by the new (transformed) values. In the case of two variable transformations, a new variable will be created for each two-variable transformation.

7.3.1 One-variable transformations

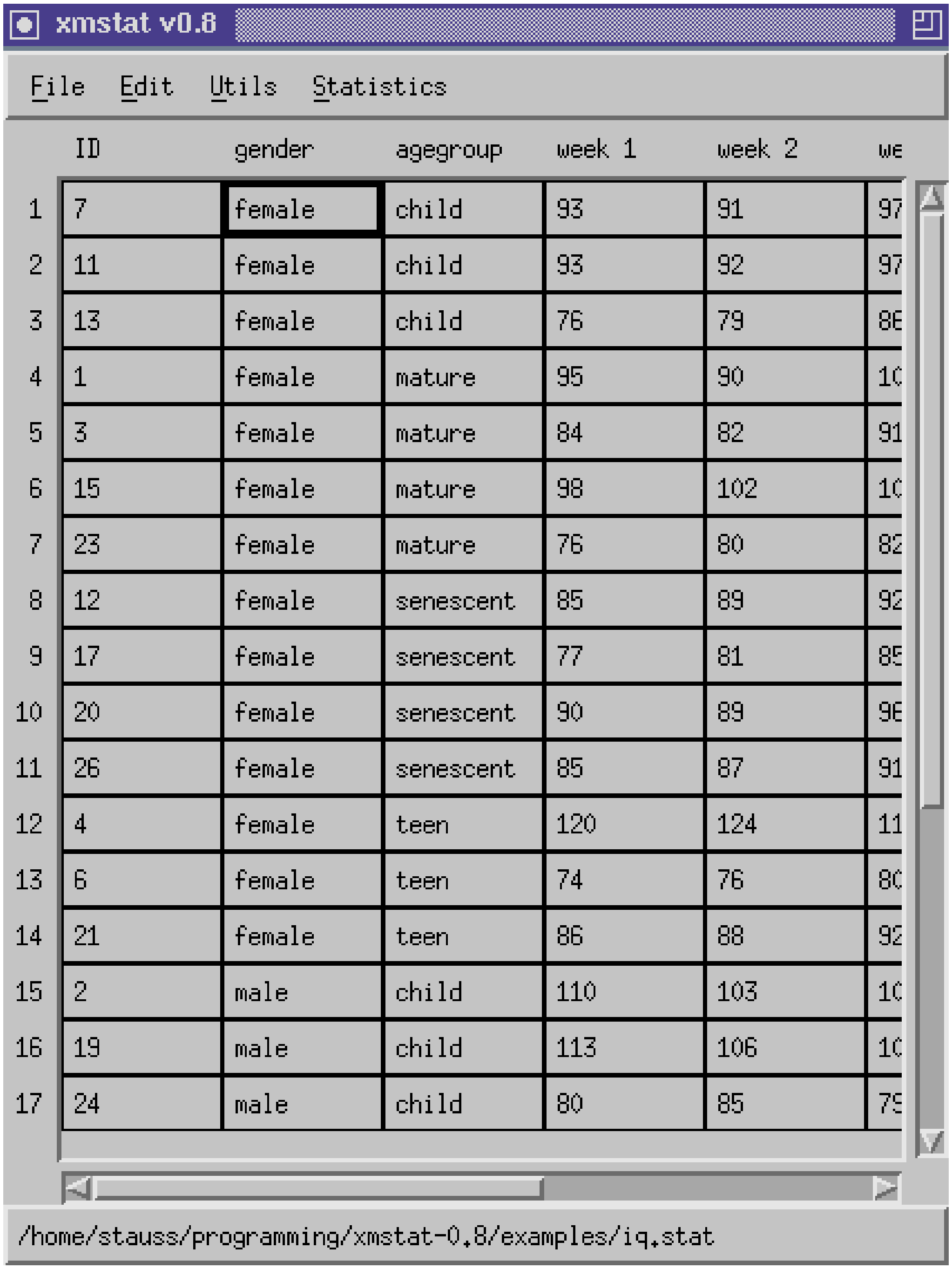
To perform a one-variable transformation, use the UTILS TRANSFORMATIONS ONE-VARIABLE menu item. The dialog shown in Fig. 7.4 will appear.

Basically, this dialog consists of a list widget, a field with radio-buttons and two text fields that allow to enter parameters for the transformations. In the list widget you can select the variables from which the transformations should be calculated. Keep in mind, that the values of the variables will be overwritten by the transformed values. Use the radio-buttons to select the transformation that you want to calculate and finally enter the values for the paramters a and b. After clicking on the OK-button, the values of the selected variables will be replaced by the transformed values.

7.3.2 Two-variables transformations

To perform two-variables transformations, use the UTILS TRANSFORMATIONS TWO-VARIABLES menu item. The dialog shown in Fig. 7.5 will appear.

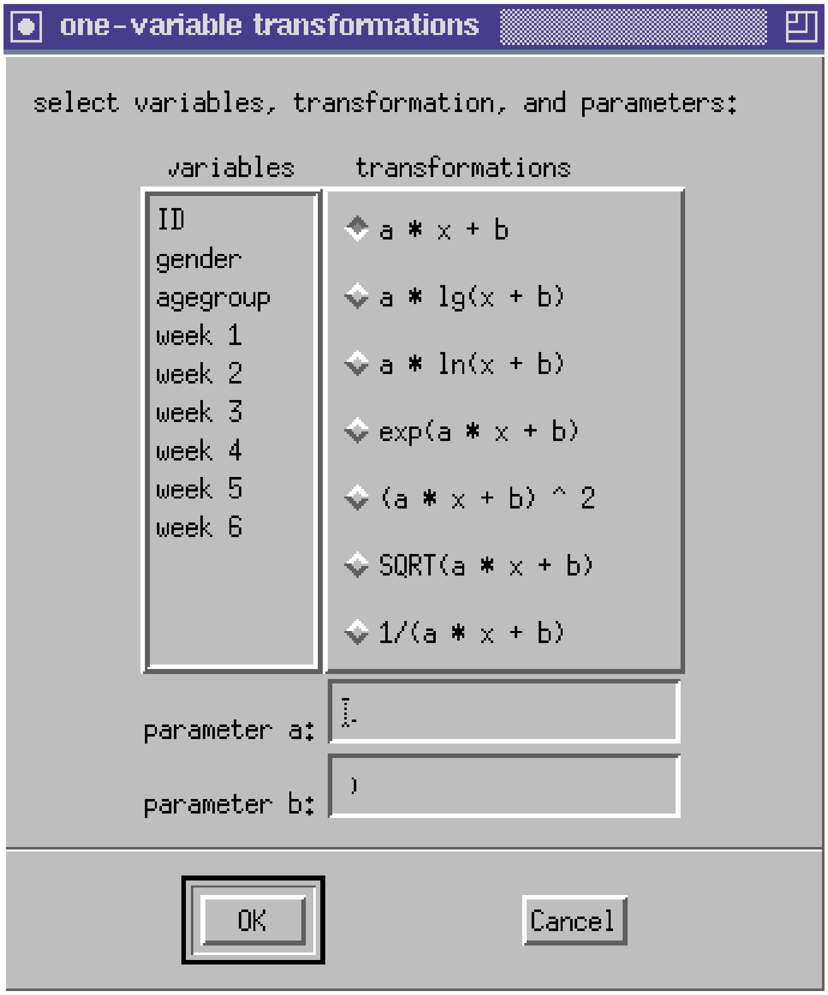
This dialog allows to fill a list of result variable names via a text field widget. In addition, two lists of variables with the same number of variables as the results variables list must be filled using the add buttons. To add variables to the 1st and 2nd variable lists, first highlight the variable names in the list on the left bottom side of the dialog and press the add button under the respective list. To delete variables from the results variable list or the lists of the first and second variable use the delete buttons. Finally, you have to select a transformation that should be applied to the lists of variables by activating the desired radio button. After pressing the OK-button the calculation will be performed and the new result variables will be added to the spreadsheet.



	ID	gender	agegroup	week 1	week 2	we
1	7	female	child	93	91	97
2	11	female	child	93	92	97
3	13	female	child	76	79	86
4	1	female	mature	95	90	10
5	3	female	mature	84	82	91
6	15	female	mature	98	102	10
7	23	female	mature	76	80	82
8	12	female	senescent	85	89	92
9	17	female	senescent	77	81	85
10	20	female	senescent	90	89	96
11	26	female	senescent	85	87	91
12	4	female	teen	120	124	11
13	6	female	teen	74	76	80
14	21	female	teen	86	88	92
15	2	male	child	110	103	10
16	19	male	child	113	106	10
17	24	male	child	80	85	79

/home/stauss/programming/xmstat-0.8/examples/iq.stat

Figure 7.3: Spreadsheet after sorting by gender and agegroup



select variables, transformation, and parameters:

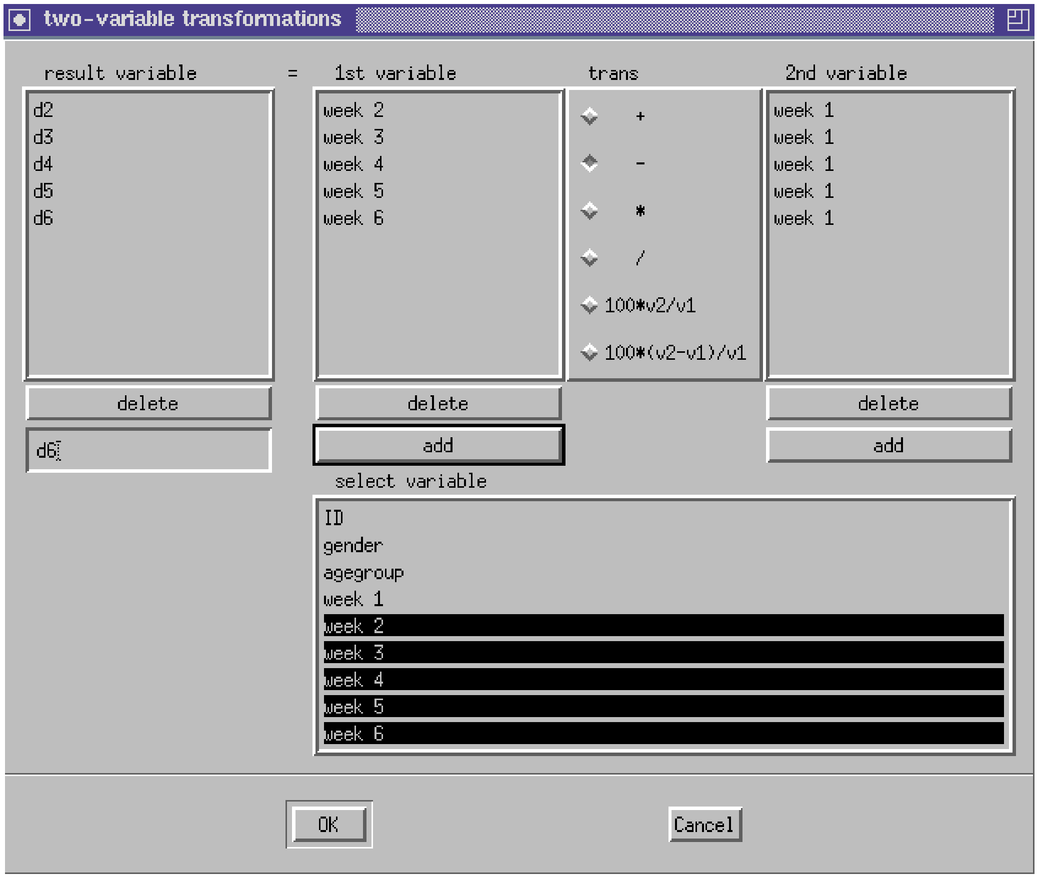
variables
- ID
- gender
- agegroup
- week 1
- week 2
- week 3
- week 4
- week 5
- week 6

transformations
- ◇ a * x + b
- ◇ a * lg(x + b)
- ◇ a * ln(x + b)
- ◇ exp(a * x + b)
- ◇ (a * x + b) ^ 2
- ◇ SQRT(a * x + b)
- ◇ 1/(a * x + b)

parameter a:

parameter b:

Figure 7.4: The ONE-VARIABLE TRANSFORMATIONS dialog



result variable	=	1st variable	2nd variable
d2		week 2	week 1
d3		week 3	week 1
d4		week 4	week 1
d5		week 5	week 1
d6		week 6	week 1

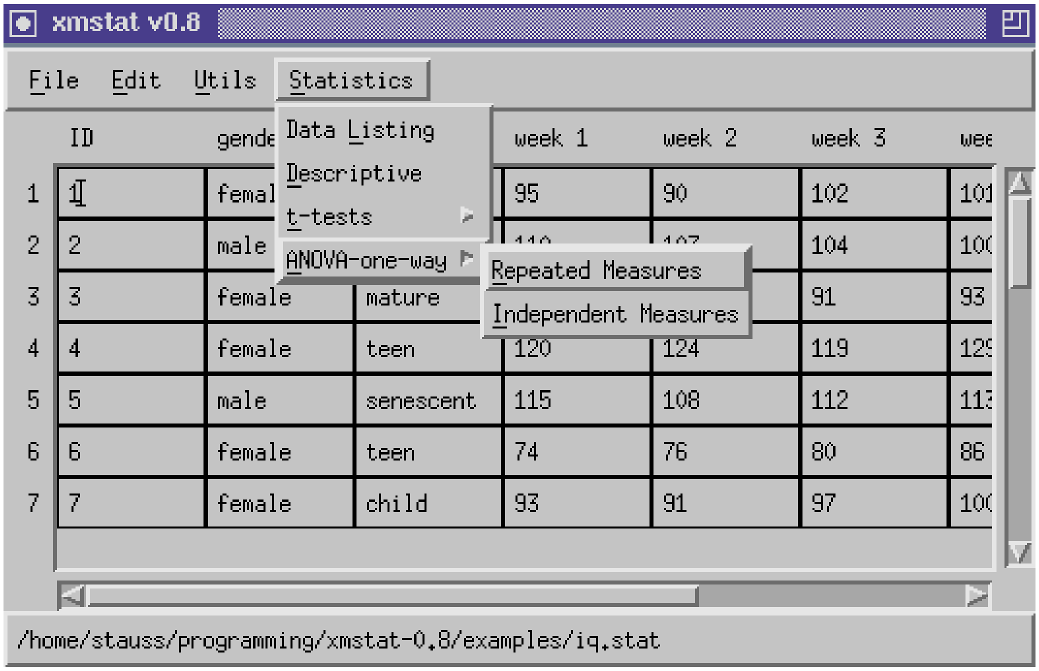
d6

Figure 7.5: The TWO-VARIABLE TRANSFORMATIONS dialog

Chapter 8

Statistics Commands

The Statistics menu offers a variety of statistical analyses tools. The database can be listed, descriptive statistics, t-tests, and analyses of variances (ANOVAs), including post-hoc tests, can be calculated (Fig. 8.1).The results are presented in a text window that allows to edit the output manually (Fig. 8.2).



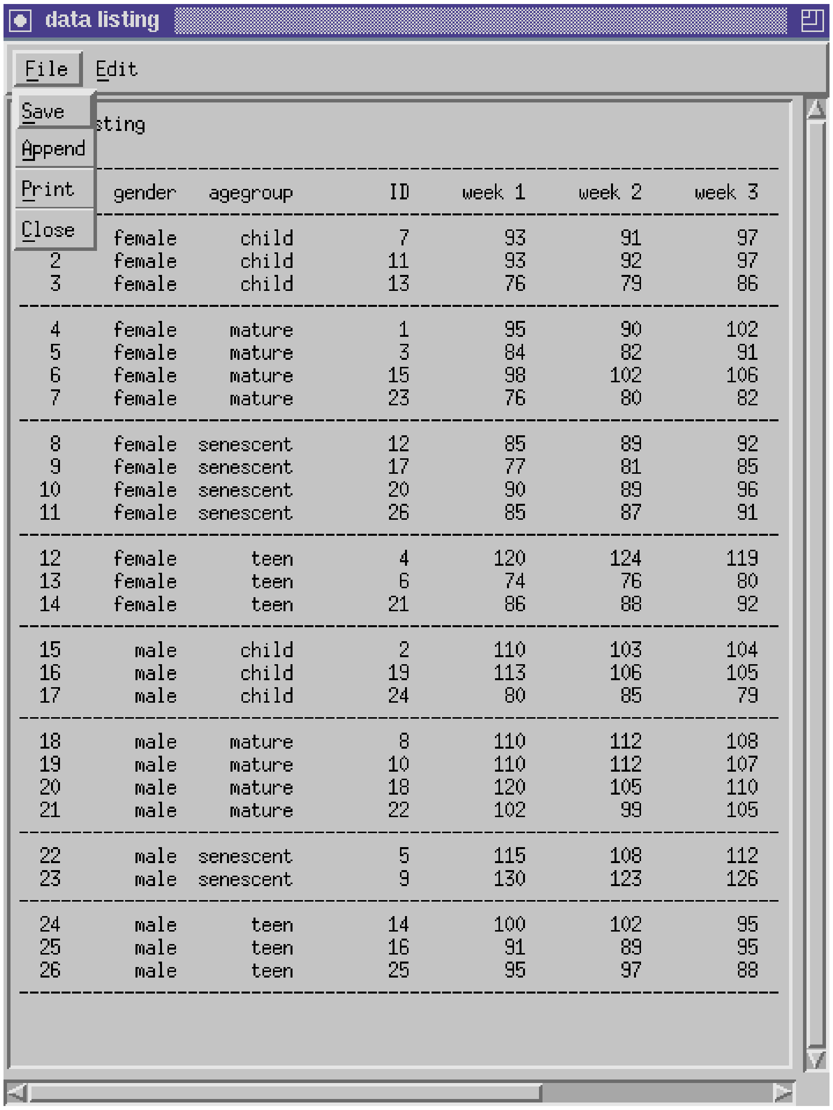
	ID	gende		week 1	week 2	week 3	wee
1	1	femal		95	90	102	101
2	2	male				104	10
3	3	female	mature			91	93
4	4	female	teen	120	124	119	12
5	5	male	senescent	115	108	112	11
6	6	female	teen	74	76	80	86
7	7	female	child	93	91	97	10

/home/stauss/programming/xmstat-0.8/examples/iq.stat

Figure 8.1: Commands in the Statistics menu

8.1 The results window

The results window (Fig. 8.2) presents the results that can be obtained from the STATISTICS menu (Fig. 8.1). It features a menubar that offers a FILE and an EDIT menu. The FILE menu offers four functions (Save, Append, Print, and Close). The EDIT menu allows to insert a pagebreak at the cursor position within the results window. The results window has editing capabilities as provided by the multiline ScrolledText Motif-widget.



```
        sting

-----------------------------------------------------------------
      gender   agegroup        ID    week 1    week 2    week 3
-----------------------------------------------------------------
      female      child         7        93        91        97
  2   female      child        11        93        92        97
  3   female      child        13        76        79        86
-----------------------------------------------------------------
  4   female     mature         1        95        90       102
  5   female     mature         3        84        82        91
  6   female     mature        15        98       102       106
  7   female     mature        23        76        80        82
-----------------------------------------------------------------
  8   female  senescent        12        85        89        92
  9   female  senescent        17        77        81        85
 10   female  senescent        20        90        89        96
 11   female  senescent        26        85        87        91
-----------------------------------------------------------------
 12   female       teen         4       120       124       119
 13   female       teen         6        74        76        80
 14   female       teen        21        86        88        92
-----------------------------------------------------------------
 15     male      child         2       110       103       104
 16     male      child        19       113       106       105
 17     male      child        24        80        85        79
-----------------------------------------------------------------
 18     male     mature         8       110       112       108
 19     male     mature        10       110       112       107
 20     male     mature        18       120       105       110
 21     male     mature        22       102        99       105
-----------------------------------------------------------------
 22     male  senescent         5       115       108       112
 23     male  senescent         9       130       123       126
-----------------------------------------------------------------
 24     male       teen        14       100       102        95
 25     male       teen        16        91        89        95
 26     male       teen        25        95        97        88
-----------------------------------------------------------------
```

Figure 8.2: Data listing presented in the results window.

8.1.1 File Save Command

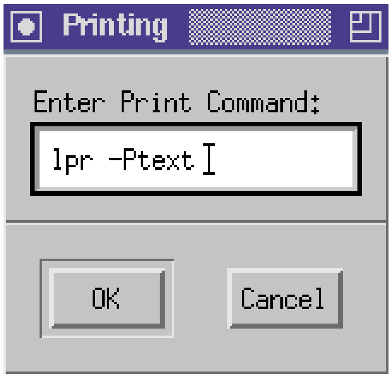
The File Save menu items allows to save the contents of the results window to an ASCII (i.e. text) file. The file name is entered via a dialog entitled Save Results on File that is similar to the dialogs shown in Fig. 4.4. If the file already exists you will be asked whether you want to overwrite the file. Alternatively, you can select a different file name.

8.1.2 File Append Command

This menu item allows to append the contents of the results window to an existing file in ASCII (i.e. text) format. The file name is entered via a dialog entitled Append Results to File that is similar to the dialogs shown in Fig. 4.4. If the file does not exist, a new file will be created. Appending results to a preexisting file is a useful feature that allows to generate an output file that holds the results of different calculations on the current database. For example, you may want to generate one output file that first contains the data listing, followed by the descriptive statistics and an ANOVA or a t-test. Once you are ready with your calculations you can load the output file into a text editor, make some final changes and print it out.

8.1.3 File Print Command

The menu item File Print allows to print the results displayed in the results window. In the dialog that appears (Fig. 8.3) you are asked to enter the command that prints ordinary text on your printer. After pressing the OK-button, the results will be printed.



Enter Print Command:

```
lpr -Ptext
```

Figure 8.3: The Printing dialog

8.1.4 File Close Command

This menu item simply closes the results window. There is not much more to say about this.

8.1.5 Edit Insert Pagebreak Command

This menu item inserts a pagebreak at the current cursor position. The same effect can be achieved by inserting a `ctr l` character (that's pressing the `Strg` key and the `l` key simultaneously) at the location where the pagebreak should appear. In the print-out of the results, a new page will be started at the location where the pagebreak was inserted.

There are more editing features in the results window that are provided by the multiline ScrolledText Motif-widget. Within the results window you can edit the text by inserting, deleting, and copying text. For example, you can highlight a text section with the mouse and paste the highlighted text to a different location by clicking the 2rd mouse button. You can even paste the highlighted text to different programs like text editors.

8.2 Data Listing

This menu item gives a listing of all variables that are defined as sort or dependent variables. If sort variables are defined, then the list is grouped into subgroups based on the sorting variables. Between each subgroup a horizontal line is inserted. An example is given in Fig. 8.2. The sort variables were the gender and the agegroup.

8.3 Descriptive Statistics

This menu item calculates descriptive statistics on the dependent variables. Don't forget to define the dependent variables from that descriptive statistics should be calculated. If sort variables are defined, the descriptive statistics are calculated on subgroups based on the sort variables. The following descriptive statistics are calculated:

- the number of observations (n).
- the minimum (min)
- the arithmetic mean (mean)
  $\bar{x} = \frac{\sum x_i}{n}$

- the maximum (max)
- the variance (var)

  $\sigma^2 = \frac{\sum (x_i - \bar{x})^2}{n-1} = \frac{\sum {x_i}^2 - \frac{\left(\sum x_i\right)^2}{n}}{n-1}$
- the standard deviation (sdev)

  $\sigma = \sqrt{\sigma^2} = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{\sum {x_i}^2 - \frac{\left(\sum x_i\right)^2}{n}}{n-1}}$
- the standard error of the mean (sem)

  $\sigma_{\bar{x}} = \sqrt{\frac{\sigma^2}{n}} = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n(n-1)}} = \sqrt{\frac{\sum {x_i}^2 - \frac{\left(\sum x_i\right)^2}{n}}{n(n-1)}}$

An example of descriptive statistics is given in Table 8.1. Descriptive statistics of the IQ-scores from women and men are calculated for all IQ-tests that were performed on six successive weeks. It looks like femals start with lower IQ-scores than men. However, while women improve with successive tests, men do not show such a trend. Whether this interpretation of the descriptive statistics is correct, can only be judged by statistical tests. How these can be performed will be explained in the following chapters.

8.4 Regression

8.5 t-tests

The Student's t-test is useful to compare the mean values of two samples. However, t-tests can only be used if the samples are normaly distributed. If the samples are not normally distributed, non-parametric tests (like the U-test described by Mann and Whitney or the Wilcoxon-test) should be applied. Student's t-tests can be computed from paired and unpaired samples. Unpaired samples are samples that are totally independent. An example would be to compare the IQ-values reached by women versus the IQ-values reached by men. In contrast, paired samples are somehow dependent from each other. For example in our test dataset, each subject performed on the IQ-test on six separate time points. Thus, the IQ-values reached by the same person at different time points are paired samples. However, since there are more than two samples (six IQ-tests) the paired t-test would not be the best choise. Student's t-tests can only compare two groups. If there are more than two groups an analysis of variance (ANOVA) should be calculated.

Table 8.1: Descriptive statistics calculated from IQ-scores of women and men on six successive weeks:

gender = female

variable	n	min	mean	max	var	sdev	sem
week 1	14	74.000	88.000	120.000	143.846	11.994	3.205
week 2	14	76.000	89.286	124.000	144.220	12.009	3.210
week 3	14	80.000	94.000	119.000	105.077	10.251	2.740
week 4	14	86.000	97.429	129.000	131.341	11.460	3.063
week 5	14	87.000	101.071	131.000	137.148	11.711	3.130
week 6	14	92.000	105.500	135.000	133.962	11.574	3.093

gender = male

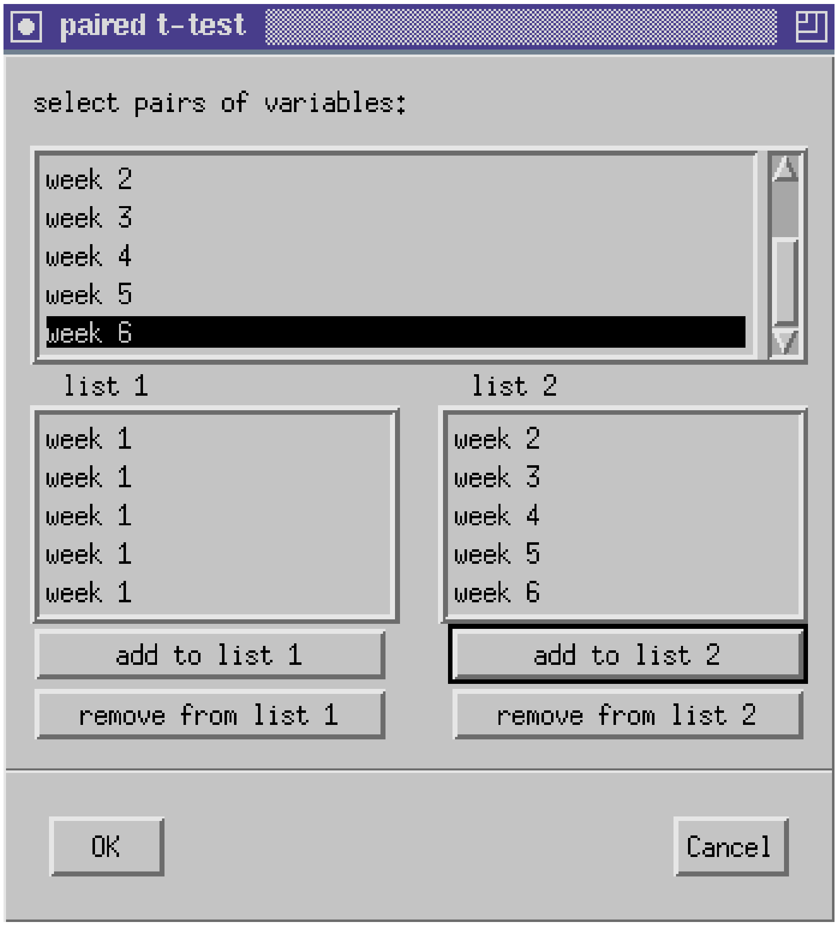
variable	n	min	mean	max	var	sdev	sem
week 1	12	80.000	106.333	130.000	183.879	13.560	3.914
week 2	12	85.000	103.417	123.000	106.447	10.317	2.978
week 3	12	79.000	102.833	126.000	148.879	12.202	3.522
week 4	12	75.000	103.167	132.000	239.424	15.473	4.467
week 5	12	82.000	103.583	125.000	157.356	12.544	3.621
week 6	12	85.000	105.583	127.000	154.629	12.435	3.590

8.5.1 Paired t-test

To compare two normally-distributed, paired data sets you may use the paired t-test. A t-value is calculated based on the n paired observations. From that t-value the probability that both samples have the same mean is calculated based on the t-distribution and the appropriate degrees of freedom ($df = n - 1$).

$$t = \frac{|\overline{x_i - y_i}|}{\sigma_{\overline{x_i - y_i}}} = \frac{\left|\frac{\sum(x_i - y_i)}{n}\right|}{\sqrt{\frac{\sum(x_i - y_i)^2 - \frac{\left(\sum(x_i - y_i)\right)^2}{n}}{n(n-1)}}}$$

To calculate paired t-tests first select sort variables if you want to calculate paired t-tests on subgroups of the database. You don't need to select dependent variables, since the variable pairs are selected in the PAIRED T-TEST dialog (Fig. 8.4) that appears if you select the STATISTICS T-TESTS PAIRED menu item. This dialog allows to select pairs of variables that will be compared by the paired t-test. The number of variables in list 1 and list 2



list 1
week 1
week 1
week 1
week 1
week 1

list 2
week 2
week 3
week 4
week 5
week 6

Figure 8.4: The PAIRED T-TEST dialog

must be equal since each corresponding variable in list 1 and list 2 are to be compared using the paired t-test. After both lists are defined, hit the OK-button to start the analysis.

The results window shows up and presents the results of the paired t-test. First the names of the two variables that are compared are listed, followed by the number of observations (n) and the degrees of freedom (*df*). In the next two columns of the results table the t-value (t) and the associated p-value (p) are given. In the last two columns the 95 % confidence interval for the difference of the means of the two groups is provided. If the confidence intervall contains 0, the two groups are likely to have the same mean. If both limits of the intervall are negative, then variable 1 is smaller than variable 2. If both limits are positive, then variable 1 is larger than variable 2.

An example is given in Table 8.2. Paired t-tests were calculated to compare the IQ-scores reached at the first test (week 1) with the IQ-scores reached at the tests at the following weeks (weeks 2-6). The calculations were performed for the subgroups of women and men by defining the sort variable "gender". In general it is not acceptable to perform multiple t-tests if more than two levels are available for a factor (in the example we have six levels of the factor "intelligent quotient") because the probability that at least one of the multiple tests would result in a Type I error increases with the number of levels. In such a scenario you should use an analysis of variance (ANOVA). Nevertheless, we calculated multiple paired t-tests in this example to demonstrate the use of the paired t-test function in WinStat. Based on the results of this paired t-test, it looks like women reached significant better IQ-scores at the 3rd, 4th, 5th, and 6th week than at the first week, while men got worse IQ-scores at the 3rd, 4th, and 5th week.

Table 8.2: Paired t-tests on the IQ-scores of women and men reached on the first testing and during the following five tests.:

gender = female

variable 1	variable 2	n	df	t	p	CI low	CI high
week 1	week 2	14	13	1.633	0.126	-2.987	0.415
week 1	week 3	14	13	8.832	0.000	-7.468	-4.532
week 1	week 4	14	13	12.050	0.000	-11.119	-7.738
week 1	week 5	14	13	23.372	0.000	-14.280	-11.863
week 1	week 6	14	13	20.908	0.000	-19.308	-15.692

gender = male

variable 1	variable 2	n	df	t	p	CI low	CI high
week 1	week 2	12	11	1.735	0.111	-0.783	6.616
week 1	week 3	12	11	2.910	0.014	0.853	6.147
week 1	week 4	12	11	3.245	0.008	1.019	5.314
week 1	week 5	12	11	3.037	0.011	0.757	4.743
week 1	week 6	12	11	0.844	0.417	-1.206	2.706

8.5.2 Unpaired t-test

Unpaired t-tests can be calculated to compare the mean values of two independent variables. An example would be to compare the IQ-scores from children with those reached by senescents. To calculate unpaired t-tests, you must first define the dependent variables (UTILS menu) on which the unpaired t-tests should be calculated. The STATISTICS T-TESTS UNPAIRED menu item will then popup a dialog box (Fig. 8.5) with two lists. The left list contains the variables that can be used to define the two groups that should be compared. In our example we select the variable "agegroup". This variable has four different levels, i.e. child, mature, senescent, and teen that are listed on the right side. If we would like to compare the effect of sex, we would select the variable "gender" that has only two levels (female and male). Since the unpaired t-test can only compare two levels of a factor we must select the two levels of the variable that defines the two groups. With the variable "gender" this is not a problem since there are only two levels. However, with the variable "agegroup" we can choose from four agegroups. To compare the IQ-scores from children and senescents we would select the respective two levels of the factor age. If more than two levels are selected in the right list when you click on the OK-button, an error message will tell you that only two levels must be selected. Please keep in mind, that it is not acceptable to perform multiple comparisons on more than two levels by the unpaired t-test, since the probability to make a type I error would increase.

Similar to the paired t-test, a t-value will be calculated based on the n_1 and n_2 observations in the two groups and a p-value will be associated with the t-value based on the degrees of freedom (df) of the unpaired t-test. The equation for the t-value and for the degrees of freedom is dependent on whether the two samples have the same variance or not. For equal variances the equations are:

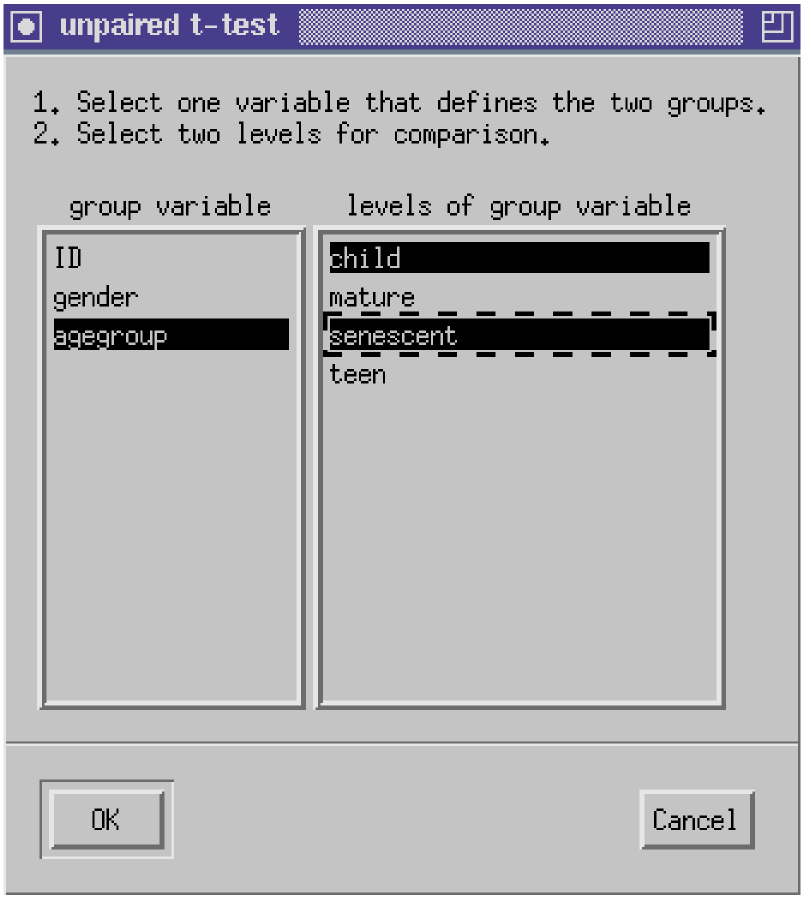
$$df = n_1 + n_2 - 2$$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1-1)\sigma_1^2+(n_2-1)\sigma_2^2}{n_1+n_2-2}\left[\frac{1}{n_1}+\frac{1}{n_2}\right]}}$$

If the variances of the two samples that should be compared using the unpaired t-test are not the same, the degrees of freedom (df) and the t-value are calculated using different equations:

$$df = \frac{\left(\frac{\sigma_1^2}{n_1}+\frac{\sigma_2^2}{n_2}\right)^2}{\frac{\left(\frac{\sigma_1^2}{n_1}\right)^2}{n_1-1}+\frac{\left(\frac{\sigma_2^2}{n_2}\right)^2}{n_2-1}}$$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{\sigma_1^2}{n_1}+\frac{\sigma_2^2}{n_2}}}$$



1. Select one variable that defines the two groups.
2. Select two levels for comparison.

Figure 8.5: The unpaired t-test dialog

The output of the unpaired t-test on the IQ-scores of children versus senescents on the six successive test is shown in Table 8.3. For each comparison two t-tests are calculated. This is necessary since the t-value is calculated by different equations depending on whether the samples have the same variance or not. For each comparison a F-test is calculated to find out whether the two samples have the same variance or not. The last column in the output table gives the result of this F-test. The letters "eq" (equal variances) in the last column means that the t-test was calculated based on the assumption that the two samples have the same variance, while the letters "ueq" (unequal variances) means that the t-test was based on different variances in the two samples. An asterisk ($*$) followed by the letters "eq" or "ueq" indicates which t-test should be used based on the F-test of equal variances. Thus, "eq$*$" means that the variances were not found to be different

($p>0.05$), while “ueq*” means that the variances are likely to be different ($p\leq0.05$).

Table 8.3: Unpaired t-tests on the IQ-scores of children versus senescents on the six successive IQ-tests:

Independent groups Student’s t-test
Group 1: agegroup = child
Group 2: agegroup = senescent

	n1	n2	df	t	p	CI low	CI high	F
week 1	6	6	10.000	-0.271	0.792	-26.163	20.496	eq*
week 1	6	6	9.136	-0.271	0.793	-26.465	20.798	ueq
week 2	6	6	10.000	-0.451	0.662	-20.808	13.808	eq*
week 2	6	6	8.556	-0.451	0.663	-21.212	14.212	ueq
week 3	6	6	10.000	-0.746	0.473	-22.590	11.257	eq*
week 3	6	6	8.663	-0.746	0.475	-22.951	11.618	ueq
week 4	6	6	10.000	-0.726	0.485	-25.100	12.767	eq*
week 4	6	6	9.226	-0.726	0.486	-25.318	12.984	ueq
week 5	6	6	10.000	-0.809	0.437	-21.895	10.228	eq*
week 5	6	6	9.807	-0.809	0.438	-21.937	10.271	ueq
week 6	6	6	10.000	-0.263	0.798	-17.389	13.722	eq*
week 6	6	6	9.964	-0.263	0.798	-17.396	13.730	ueq

The first column in the output table gives the variable for which the independent t-test was calculated. The next two columns are the number of observations in the two groups, followed by the degrees of freedom. The next two columns give the t-value and the respective p-value. Then, the confidence intervall for the difference of the mean values of the two samples are given. The last column, finally, gives the result of the F-test for equal variances. It looks like the variances in the IQ-scores from children and senescent are similar, since in all comparisons the F-test of equal variances revealed a p-value larger than 0.05, as indicated by “eq*”. Thus, the independent t-tests calculated based on equal variances (marked by “eq*”) should be used to compare the two groups. In addition, the mean values of the IQ-scores reached by children and senescents are not statistically significant different, since the p-values of the independent t-tests are all larger than 0.05.

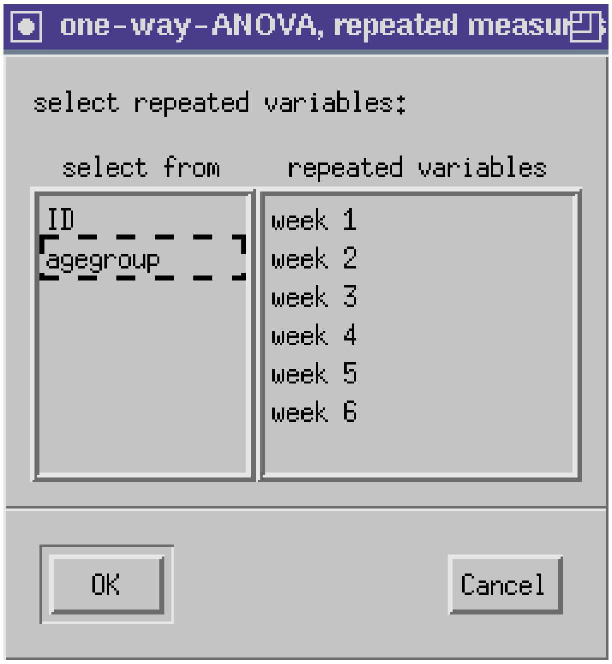
8.6 ANOVA-one-way

If the mean values of more than two normally distributed groups of samples need to be compared, the analysis of variance is the appropriate statistical test. A F-value is calculated and based on the F-distribution a p-value is estimated that gives the probability that all mean values are identical. In other words, if the p-value is smaller than a pre-defined critical value (p.e. $p<0.05$) then at least two of the groups have different mean values. In the one-way ANOVA there is only one factor. This one factor however, usually has more than two levels. If the levels are independent from each other, than an independent measures ANOVA (completely randomized design) should be calculated. An example would be to compare the IQ-scores reach on the first test day by children, teens, matures, and senescents. The independent factor would be the age and the four levels would be the four agegroups. The dependent variable would be the IQ-scores on the first week. On the other hand, factors in a one-way ANOVA can also be dependent from each other. An example would be the IQ-scores reached on the six successive testings. Since it is possible, that a learning effect takes place when the tests are repeated, the IQ-scores reached on successive testings can not be considered to be independent. In such a case, a repeated measures ANOVA (randomized block design) should be performed.

The analysis of variance only provides information as to whether at least two mean values differ. There is, however, no information on which mean values differ from each other. Since it is often desirable to know which groups differ, post-hoc tests can be performed. In such post-hoc tests, all possible combinations of mean values ($n*(n-1)/2$) will be compared. Thus information on which mean values differ from each other is provided. There are a number of post-hoc tests described in the literature. Examples are the Scheffé test, the Tukey test, the Newman-Keuls test, or the Fisher test. These post-hoc tests differ in their “strength” or “power”. In other words, it is possible that one post-hoc test finds differences between two groups while another post-hoc test does not. Therefore it is important to know some characteristics of the different post-hoc tests, that are discussed in a later section.

8.6.1 Repeated Measures

To calculate a repeated measures ANOVA use the STATISTICS ANOVA-ONE-WAY REPEATED MESURES menu item. A dialog with two lists pops up (see Fig. 8.6). In the left list, all variables that are not sort variables are listed. By clicking on the variable names, the variables are moved to the right list which represents the repeated measurements that should be compared by the ANOVA. For example, you may want to select the six variables that hold the IQ-scores reached on the six weeks. After hitting the OK-button, the results of the repeated measurements ANOVA will be presented in the results window. If sort variables have been defined (p.e. the gender or/and the agegroup), the ANOVA will be calculated for all respective subgroups.



select from:
ID
agegroup

repeated variables:
week 1
week 2
week 3
week 4
week 5
week 6

Figure 8.6: The ANOVA-ONE-WAY, REPEATED MEASURES dialog

On top of the results window, the ANOVA table (see Table 8.4) is displayed, followed by the post-hoc tests. In the ANOVA table, the total variance of all samples of all groups is separated into the variance that can be attributed to the intra-individual variance (within the six IQ-scores of each subject), inter-individual variance (between the subjects), and in the variance that is caused by the sampling variability (error). A F-value is calculated for the intra-individual variance (within) and for the inter-individual variance (between). Based on the F-distribution and the respective degees of freedom, these F-values are associated with a p-value that is given in the last column of the ANOVA table. If the p-value of the intra-individual (within) variance is small (p.e. $p<0.05$), than at least two of the levels of the repeated measurements factor differ. In our example this would mean that repeated IQ-tests reveal different results. If the p-value of the inter-individual (between) variance is small (p.e. $p<0.05$), this means that the subjects are not very homogenious. In our example it would mean that some subjects received significant different (higher or lower) IQ-scores than some other subjects.

Source	df	sum of squares	mean squares	F	p
within	5	3234.0952	646.8190	127.0561	0.0000
between	13	10011.8105	770.1393	151.2802	0.0000
error	65	330.9028	5.0908		
total	83	13576.8086			

Table 8.4: 1-way-ANOVA table for repeated measures

Calculation of the various values in the repeated measures ANOVA table is performed according to the following scheme:

Source	df	sum of squares	mean squares	F	p
within	p-1	SSG	MSG	MSG/MSE	$F_{p-1,\ n-p-b+1}$
between	b-1	SSS	MSS	MSS/MSE	$F_{b-1,\ n-p-b+1}$
error	n-p-b+1	SSE	MSE		
total	n-1	SS (Total)			

p:	number of groups (repeated measurements)
b:	number of subjects (observations)
n:	total number of data values (p * b)
$\bar{x}_{G_i}$:	mean of all subjects for the i^{th} measurement
$\bar{x}_{S_i}$:	mean of all repeated measurements for the i^{th} subject
$\bar{x}$:	mean of all data values in the database

$$SSG\ (group) = \sum_{i=1}^{p} b(\bar{x}_{G_i} - \bar{x})^2$$

$$SSS\ (subject) = \sum_{i=1}^{b} p(\bar{x}_{S_i} - \bar{x})^2$$

$$SS\ (total) = \sum_{i=1}^{n} (x_i - \bar{x})^2$$

$$SSE\ (error) = SS - SSG - SSS$$

$$MSG = \frac{SSG}{p-1}$$

$$MSS = \frac{SSS}{b-1}$$

$$MSE = \frac{SSE}{n-b-p+1}$$

8.6.2 Independent Measures

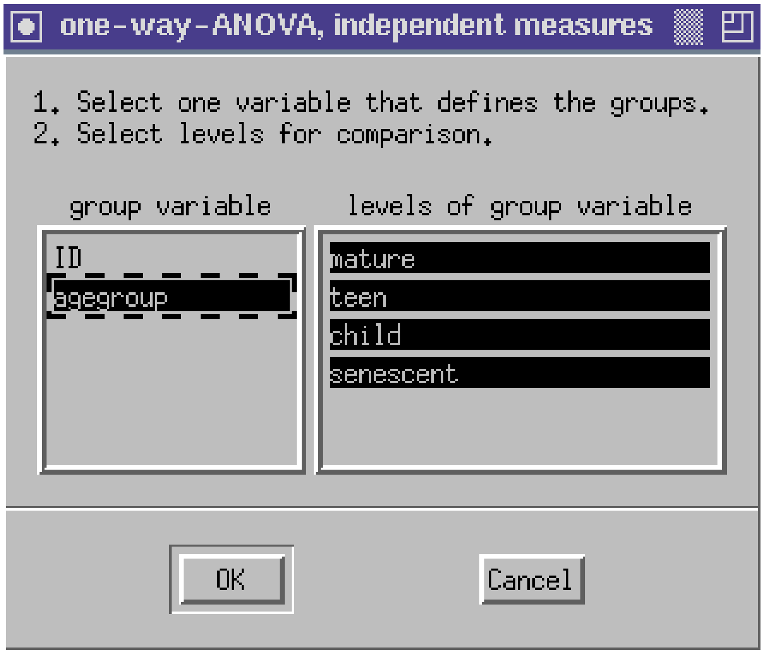
To calculate an independent measures ANOVA, you first have to select sort variables if calculations on subgroups need to be performed. In addition, you must define dependent variables on which the independent measures ANOVA should be calculated. Once the sort and dependent variables have been defined, you can access the ONE-WAY-ANOVA, INDEPENDENT MEASURES dialog (see Fig. 8.7) via the STATISTICS ANOVA-ONE-WAY INDEPENDENT MEASURES menu item. The dialog consists of two lists. The left list shows all variables that are not sort or dependent variables. From those variables you can select the variable that defines the levels of the factor for the independent measures ANOVA. If you have selected the variable that defines the levels of the factor, the right list will contain all levels that are included in this variable. From these levels (in the right list) you can select those levels, that you want to include in the independent measures ANOVA. For example you may want to select the variable "agegroup" to define the levels of the factor for the independent measures ANOVA. This factor consists of four levels (i.e. mature, teen, child, and senescent). By default, all levels are selected. If you don't want to exclude any levels you can start calculation of the ANOVA by clicking on the OK-button. The results will be displayed in the results window.

For each subgroup as many independent measures ANOVAs are calculated as you have selected dependent variables. In the ANOVA table (see Table 8.5) the total variance in all levels of the factor is separated into the inter-individual variance (between) and the variance caused by the sampling variability (error). For the inter-individual variance a F-value and a corresponding p-value is calculated. A small p-value (p.e. $p<0.05$) means that at least two levels differ from each other. In our example it would mean that the IQ-scores reached by subjects belonging to different agegroups differ. Or in other words, IQ-scores would be dependent on the age of the subjects. However, since in our example $p=0.8412$ (see Table 8.5) there are no effects of age on the IQ-scores. This makes sense, since IQ-scores are already age-adjusted.

week 1	df	sum of squares	mean squares	F	p
between	3	143.1667	47.7222	0.2764	0.8412
error	10	1726.8333	172.6833		
total	13	1870.0000			

Table 8.5: 1-way-ANOVA table for independent measures

Calculation of the various values in the independent measures ANOVA



one-way-ANOVA, independent measures

1. Select one variable that defines the groups.
2. Select levels for comparison.

Figure 8.7: The ANOVA-ONE-WAY, INDEPENDENT MEASURES dialog

table is performed according to the following scheme:

Source	df	sum of squares	mean squares	F	p
between	p-1	SSG	MSG	MSG/MSE	$F_{p-1,\ n-p}$
error	n-p	SSE	MSE		
total	n-1	SS (Total)			

p: number of groups (independent measurements)
n_i: number of observations (subjects) in the i^{th} group
n: total number of data values ($\sum_{i=1}^{p} n_i$)
$\bar{x}_i$: mean of all subjects in the i^{th} group
x_{ij}: j^{th} data value in the i^{th} group
$\bar{x}$: mean of all data values in the database

$$SSG\ (group) = \sum_{i=1}^{p} n_i(\bar{x}_i - \bar{x})^2$$

$$SSE\ (error) = \sum_{i=1}^{p}\sum_{j=1}^{n_i}(x_{ij} - \bar{x}_i)^2$$

$$SS\ (total) = SSG\ +\ SSE$$

$$MSG = \frac{SSG}{p-1}$$

$$MSE = \frac{SSE}{n-p}$$

8.6.3 Post-hoc tests

An ANOVA is usually computed if the mean values of more than two normally distributed groups need to be compared. However, the ANOVA only answers the question as to whether at least two groups differ from each other. To investigate which of the groups differ from each other, post-hoc tests can be calculated. Currently, the Scheffé, Tukey, Newman-Keuls, and Fisher post-hoc tests are supported in WinStat.

Scheffé test

The Scheffé test is valid only, if the ANOVA table reveals a significant p-value. A $\hat{F_S}$ is calculated and based on ν_1 and ν_2 degrees of freedom a p-value is obtained from the F-distribution. $\hat{F_S}$, ν_1, and ν_2 are calculated according to:

ν_1: p-1
ν_2: n-p
p: number of groups
n_i: number of data values in the i^{th} group
n: total number of data values in the database ($\sum_{i=1}^{p} n_i$)
$\bar{x_i}$: mean value of the i^{th} group
MSE: MSE from ANOVA table

$$\hat{F_S} = \frac{(\bar{x_a} - \bar{x_b})^2}{MSE\left(\frac{1}{n_a} + \frac{1}{n_b}\right)(k-1)}$$

Fisher test

The Fisher test is also called the “least significant difference method (LSD)” and is based on the t-test. Like the Scheffé test, this test is only valid if the p-value in the ANOVA table is significant. If the ANOVA is significant, then each mean is compared with each other mean using a t-test. Since homogeneity of variance is typically assumed for Fisher’s LSD procedure, the estimate of variance is based on all the data, not just on the data for the two groups being compared. In order to make the relationship between Fisher’s LSD and other methods of computing pairwise comparisons clear, the formula for the studentized t (t_s) rather than the usual formula for t is used:

p: number of groups
n_i: number of data values in the i^{th} group
n: total number of data values in the database ($\sum_{i=1}^{p} n_i$)
$\bar{x_i}$: mean value of the i^{th} group
MSE: MSE from ANOVA table
n_h: harmonic mean of the sample sizes of the two groups $\frac{2}{\frac{1}{n_a}+\frac{1}{n_b}}$

$$t_s = \frac{\bar{x_a} - \bar{x_b}}{\sqrt{\frac{MSE}{n_h}}}$$

Based on t_s, a number of degrees of freedom according to MSE ($df = n - p$), and two mean values, a p-value is obtained from the studentized range distribution. The Fisher test may be appropriate if less than six groups are compared.

Newman-Keuls test

For the Newman-Keuls test, the studentized t_s-value is calculated in the same way as for the Fisher test. However, the p-value is obtained from the studentized range distribution based on the same degrees of freedom as in the Fisher procedure, but on a number of mean values that equals the difference of the ranks of the mean values of the two groups that are compared plus one. To this end, the groups in the ANOVA are rank-ordered by the mean values of the groups from smallest to largest. Then, the smallest mean is compared to the largest mean using the studentized t_s. If the test is not significant, then no pairwise tests are significant and no more testing is done. If the difference between the largest mean and the smallest mean is significant, then the difference between the smallest mean and the second largest mean as well as the difference between the largest mean and the second smallest mean are tested. This procedure is repeated until all groups are compared. The difference to the Fisher test, however, is that the p-value is obtained from the studentized range distribution based on a number of mean values that correspondes to the number of rankes spaned by the two groups that are compared. The basic idea is that when a comparison that spans k means is significant, comparisons that span k-1 means within the original span of k means are performed. In contrast to the Scheffé and Fisher tests, the Newman-Keuls test is also valid, if the p-value calculated in the ANOVA table is not significant. The Newman-Keuls test should be used if more than seven groups are compared.

Tukey test

The Tukey test is performed in a similar way as the Fisher test. However, the p-value is obtained from t_s based on the same degrees of freedam as in the Fisher test, but based on a number of mean values that is equal to the number of groups in the ANOVA. Thus, the Tukey test is much more strict than the Fisher test, i.e. may be not significant, whereas the Fisher test is significant. The Tukey test is also valid if the p-value obtained in the ANOVA table is not significant.

8.7 ANOVA-two-way

In the case of the two-way ANOVA there are two factors with several levels each that impacts the dependent variable. Now the levels of these factors can be independent or dependent. The effect of independent factors is usually tested in different subjects, whereas the effect of dependent factors is often tested in the same individual subjects. Thus, in WinStat, independent factors are arranged as columns (variables) containing the information on the level of the independent factor for each observation. Thus, there is one variable for each independent factor. In contrast, dependent variables have one column for each level of the dependent variable, containing the values of the dependent variable for that level of the dependent variable. Thus, for dependent factors there are as many variables (columns) as there are levels in the factor.

8.7.1 Repeated-Repeated Design

Let's assume that several subjects take IQ-tests repeatedly on a weekly basis over a time period of 6 weeks (W1, W2, ..., W6). Let's also assume that during each week, each test-taker takes 3 differently designed IQ tests presented on different test forms (Fa, Fb, Fc).

In this experiment we could ask the question if the IQ-scores obtained from the three different test forms differ from each other. In addition, it would be interesting to know if there is an improvement in the IQ-scores if the test is replicated in subsequent weeks. Finally, we could ask if it depends on the test form if there are improvements in the IQ-scores from week to week. An IQ-test may be designed such that there is no improvement in the resulting IQ-scores if the test is taken repeatedly by the same subject (given that the IQ of the subject did not change due to education, brain disease, or other factors).

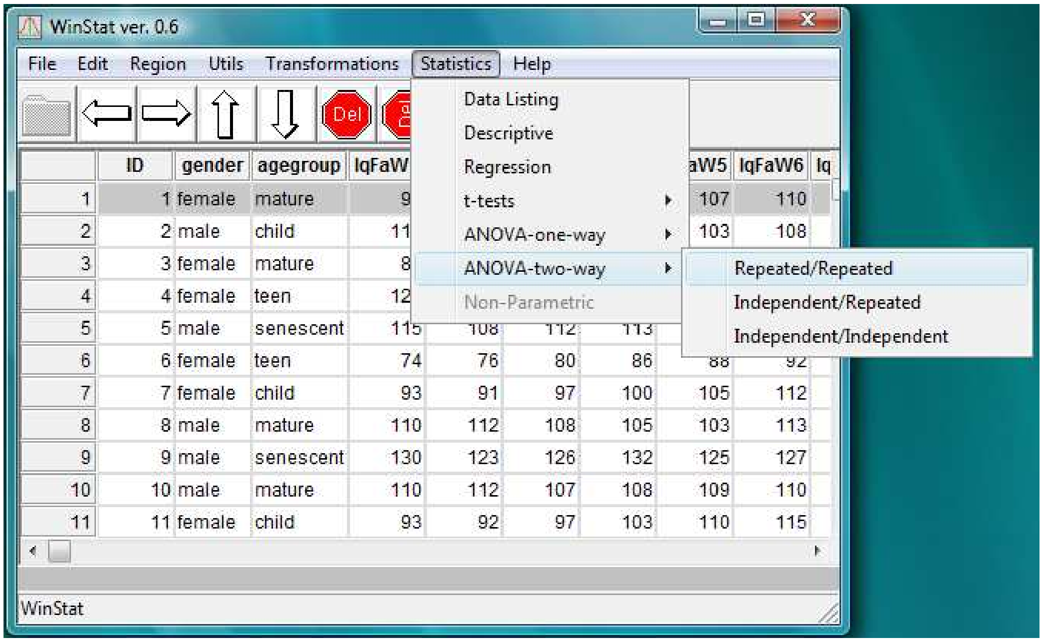
Forthermore, the data structure reveals that the IQ-tests were taken by children, teens, mature, and senescent subjects of both genders. We may therefore, perform statistical analyses of subgroups of the data (e.g., only for females or males or only for one of the 4 age groups). Such subgroups specific analyses are possible by sorting the data by gender or agegroup before actually running the 2-way ANOVA. The layout of the data set used in this example is shown in Table 8.6.

ID	gender	agegroup	IqFaW1	IqFaW2	IqFaW3	IqFaW4	IqFaW5	IqFaW6	IqFbW1	IqFbW2
1	female	mature	95	90	102	101	107	110	94	96
2	male	child	110	103	104	100	103	108	109	110
3	female	mature	84	82	91	93	97	100	83	81
4	female	teen	120	124	119	129	131	135	121	117
5	male	senescent	115	108	112	113	117	114	117	115
6	female	teen	74	76	80	86	88	92	70	72
7	female	child	93	91	97	100	105	112	94	96
8	male	mature	110	112	108	105	103	113	111	108
9	male	senescent	130	123	126	132	125	127	132	127
10	male	mature	110	112	107	108	109	110	111	107
11	female	child	93	92	97	103	110	115	90	93
12	female	senescent	85	89	92	91	97	104	84	82
13	female	child	76	79	86	91	87	98	72	77
14	male	teen	100	102	95	97	98	99	98	97
15	female	mature	98	102	106	111	113	115	94	98
16	male	teen	91	89	95	88	87	93	90	93
17	female	senescent	77	81	85	89	91	94	78	80
18	male	mature	120	105	110	122	117	116	121	123
19	male	child	113	106	105	111	107	114	110	112
20	female	senescent	90	89	96	99	103	109	89	91
21	female	teen	86	88	92	91	97	102	86	87
22	male	mature	102	99	105	95	101	97	103	100
23	female	mature	76	80	82	87	93	96	77	75
24	male	child	80	85	79	75	82	85	81	83
25	male	teen	95	97	88	92	94	91	95	98
26	female	senescent	85	87	91	93	96	95	86	85

IqFbW3	IqFbW4	IqFbW5	IqFbW6	IqFcW1	IqFcW2	IqFcW3	IqFcW4	IqFcW5	IqFcW6
93	93	97	93	95	86	102	100	107	105
107	110	109	108	108	99	99	100	102	105
84	82	83	81	80	81	87	93	92	101
120	121	122	117	121	124	116	128	128	133
113	112	116	112	113	108	110	111	113	111
72	72	72	74	74	72	78	85	84	89
91	94	92	91	89	86	94	98	102	109
109	108	108	107	107	111	105	100	103	112
131	133	132	131	127	124	127	129	124	124
111	110	107	107	107	111	106	106	105	110
90	92	92	93	91	91	95	101	109	113
83	86	87	87	86	87	89	87	92	101
74	79	79	76	73	77	84	92	84	94
99	100	98	101	98	100	96	95	93	97
98	95	97	101	99	98	104	106	109	113
89	88	88	93	92	88	91	89	86	89
80	75	80	76	74	81	85	84	92	93
119	122	120	118	120	105	108	122	114	111
114	116	112	115	111	105	100	109	107	112
91	87	87	90	91	84	97	97	98	106
83	85	86	86	84	88	90	88	94	99
101	101	103	102	102	95	106	94	96	96
79	74	76	76	74	81	77	84	92	93
78	80	79	78	80	82	78	74	82	86
96	96	98	98	91	97	83	88	91	90
84	82	86	85	80	83	91	93	93	90

Table 8.6: Example data file for a 2-way-ANOVA with two repeated measures. The repeated measures are the test forms (fa, fb, fc) and the weeks of test replication (w1, w2, ..., w6).

To actually calculate the 2-way ANOVA for two repeated measures (test forms and weeks of test replication) we have to open the respective dialog box and enter the repeated variables. The 2-way ANOVA for two repeated measures is available through the STATISTICS ANOVA-TWO WAY REPEATED/REPEATED menu item as shown in Fig. 8.8.

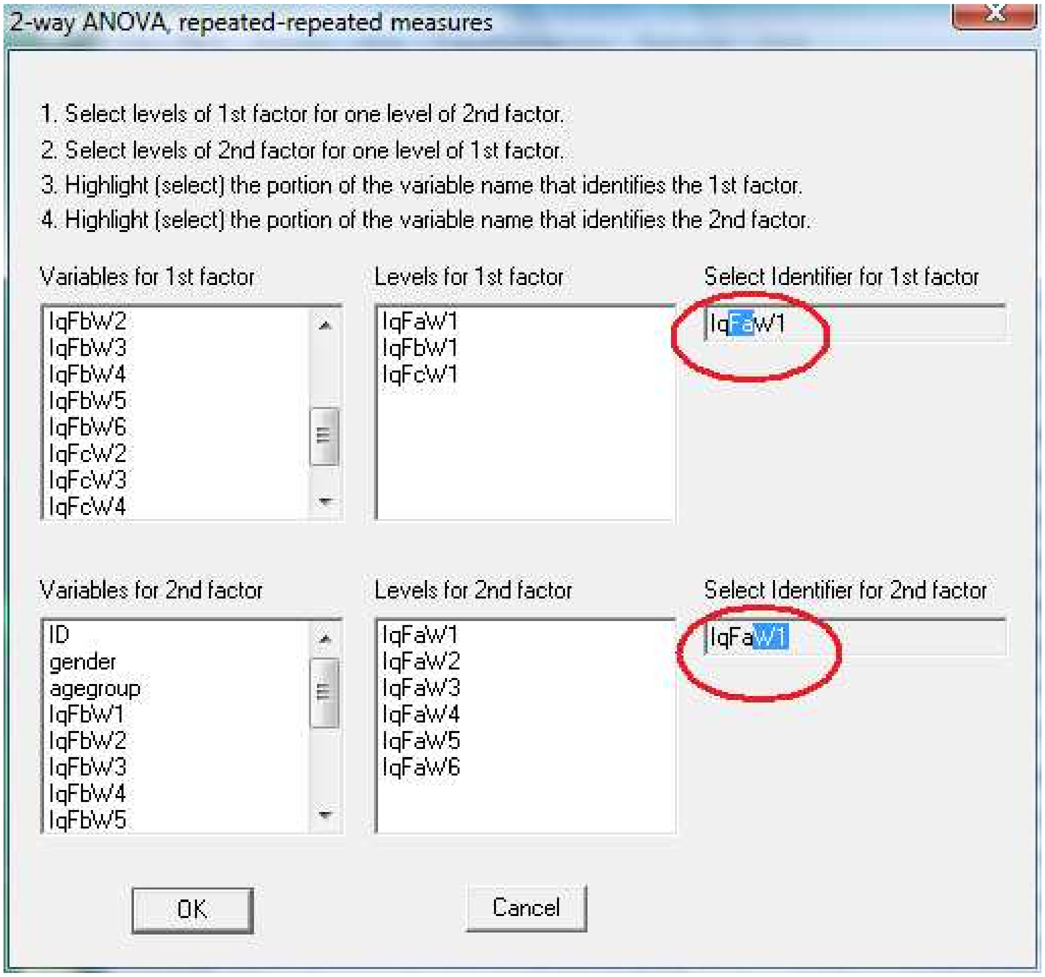


	ID	gender	agegroup	IqFaW				aW5	IqFaW6	Iq
1	1	female	mature	9				107	110	
2	2	male	child	11				103	108	
3	3	female	mature	8						
4	4	female	teen	12						
5	5	male	senescent	115	108	112	113			
6	6	female	teen	74	76	80	86	88	92	
7	7	female	child	93	91	97	100	105	112	
8	8	male	mature	110	112	108	105	103	113	
9	9	male	senescent	130	123	126	132	125	127	
10	10	male	mature	110	112	107	108	109	110	
11	11	female	child	93	92	97	103	110	115	

Figure 8.8: Menu option for ANOVA-two way, Repeated/Repeated

This menu item brings up the 2-WAY ANOVA REPEATED-REPEATED MEASURES dialog box as shown in Fig. 8.9. Since the data for the individual levels of the two repeated parameters are arranged in columns (or variables) in WinStat, the levels used for the repeated/repeated measures 2-way ANOVA is encoded in the variable names. Please note that the repeated measures for the IQ-test forms are identified in the variable names by a portion (substring) of the variable name that consists of "F" (for "Form") and a small capital letter (for the different IQ-forms). Thus, Fa denotes IQ-form a, Fb denotes IQ-form b, and Fc denotes IQ-form c. We also could have been using a different naming convention, such as IQF01, IQF02, etc. The second repeated measure corresponds to the weekly repetitions and is encoded as "W1", "W2", "W3", etc. Therefore, a variable name of "IQFbW4" identifies IQ values obtained by IQ-test form b during week 4.

In the dialog box, first select all levels of the first repeated measure (factor) for one level of the second repeated measure (factor). In this example, we have to select the variables "IqFaW1", "IqFbW1", and "IqFcW1" to



1. Select levels of 1st factor for one level of 2nd factor.
2. Select levels of 2nd factor for one level of 1st factor.
3. Highlight (select) the portion of the variable name that identifies the 1st factor.
4. Highlight (select) the portion of the variable name that identifies the 2nd factor.

Variables for 1st factor: IqFbW2, IqFbW3, IqFbW4, IqFbW5, IqFbW6, IqFcW2, IqFcW3, IqFcW4

Levels for 1st factor: IqFaW1, IqFbW1, IqFcW1

Select Identifier for 1st factor: IqFaW1

Variables for 2nd factor: ID, gender, agegroup, IqFbW1, IqFbW2, IqFbW3, IqFbW4, IqFbW5

Levels for 2nd factor: IqFaW1, IqFaW2, IqFaW3, IqFaW4, IqFaW5, IqFaW6

Select Identifier for 2nd factor: IqFaW1

Figure 8.9: Dialog box for ANOVA-two way, Repeated/Repeated

identify the three levels of the first repeated factor, i.e., IQ-forms a, b, and c. Second, we have to select all levels of the second repeated measure (factor) for one level of the first repeated measaure (factor). In this example, we select “IqFaW1”, “IqFaW2”, “IqFaW3”, “IqFaW4”, “IqFaW5”, and “IqFaW6” to identify the 6 levels of the second repeated measure, i.e., week 1, week 2, week 3, week 4, week 5, and week 6. Finally, we have to highlight the portion (substring) of the variable names that identify the levels of the 2 repeated measures (factors) in the edit field for each repeated measure. In this example, we highlight (by dragging the mouse with the first mouse button pressed or by using the shift key in combination with the arrow keys) the substrings “Fa” and “W1” as shown by the red circles in Fig. 8.9. Since there are 3 IQ-forms and 6 weeks of test repetition, the analysis will use a total of 18 variables of the data file.

With this setup in the dialog box (Fig. 8.9) we are ready to actually run the ANOVA by clicking the OK button. The results of the 2-way ANOVA will be presented as shown in Table 8.7.

ANOVA (two-way) for two repeated measures

Source	df	Sum of Square	Mean Square	F	P
Subjects	25	79893.35156	3195.73406		
Fa	2	1045.72266	522.86133	8.595	0.000619
error	50	3041.83350	60.83667		
W1	5	2208.30078	441.66016	14.566	0.000000
error	125	3790.25635	30.32205		
FaW1	10	1104.12390	110.41239	12.376	0.000000
error	250	2230.30957	8.92124		
Total	467	93313.89844			

Table 8.7: 2-way-ANOVA table for two repeated measures

Calculation of the values in the 2-way-ANOVA table for two repeated measures is rather complicate. With the help of the Hyperstat internet page by David M. Lane [4], I was able to figure out the equations to calculate the various sums of squares. The equations are provided below:

ANOVA (two-way) for two repeated measures

Source	df	Sum of Square	Mean Square	F	P
Subjects	df_S	SSS	MSS		
Factor 1	df_F1	SSF1	MSSF1	MSSF1/MSSF1E	$F_{df\_F1,\ df\_F1E}$
Error	df_F1E	SSF1E	MSSF1E		
Factor 2	df_F2	SSF2	MSSF2	MSSF2/MSSF2E	$F_{df\_F2,\ df\_F2E}$
Error	df_F2E	SSF2E	MSSF2E		
Interaction	df_F1F2	SSF1F2	MSSF1F2	MSSF1F2/MSSF1F2E	$F_{df\_F1F2,\ df\_F1F2E}$
Error	df_F1F2E	SSF1F2E	MSSF1F2E		
Total	df_total	SST			

n: number of subjects
i: number of levels of the first repeated factor
j: number of levels of the second repeated factor
df_S: (n-1)
df_F1: (i-1)
df_F1E: (n-1)*(i-1)
df_F2: (j-1)
df_F2E: (n-1)*(j-1)
df_F1F2: (i-1)*(j-1)
df_F1F2E: (n-1)*(i-1)*(j-1)
df_total: (i*j*n)-1

ns_k:	number of repeated values for subject k (lF1 + lF2)
$\bar{xs}_k$	mean of all repeated values from subject k
$\bar{x}$:	mean of all values (all subjects, all repetitions)
$lF1$:	number of levels for factor 1
$lF2$:	number of levels for factor 2
$nF1$:	number of values for factor 1 (lF1 * n)
$nF2$:	number of values for factor 2 (lF2 * n)
$x\bar{F}1_l$:	mean of all values from level l of factor 1 (all subjects, all levels of factor 2)
$x\bar{F}2_m$:	mean of all values from level m of factor 2 (all subjects, all levels of factor 1)
$x_{k,l,m}$:	value of subject k, at level l of first factor and level m of second factor
$xs\bar{F}1_{km}$:	mean of all values from level m of factor 2 from subject k
$xs\bar{F}2_{kl}$:	mean of all values from level l of factor 1 from subject k
$xF\bar{1}F2_{l,m}$:	mean of all values from level l of factor 1 and level m of factor 2 from all subjects

$$SSS = \sum_{k=1}^{n} ns_k(\bar{xs}_k - \bar{x})^2$$

$$SSF1 = \sum_{l=1}^{lF1} nF2(x\bar{F}1_l - \bar{x})^2$$

$$SSF1E = \sum_{l=1}^{lF1} \sum_{k=1}^{n} (xs\bar{F}2_{kl} - x\bar{F}1_l - \bar{xs}_k + \bar{x})^2$$

$$SSF2 = \sum_{m=1}^{lF2} nF1(x\bar{F}2_m - \bar{x})^2$$

$$SSF2E = \sum_{m=1}^{lF2} \sum_{k=1}^{n} (xs\bar{F}1_{km} - x\bar{F}2_m - \bar{xs}_k + \bar{x})^2$$

$$SSF1F2 = \sum_{l=1}^{lF1} \sum_{m=1}^{lF2} n(xF\bar{1}F2_{l,m} + \bar{x} - x\bar{F}1_l - x\bar{F}2_m)^2$$

$$SSF1F2E = SST - SSS - SSF1 - SSF1E - SSF2 - SSF2E - SSF1F2$$

$$SST = \sum_{k=1}^{n} \sum_{l=1}^{lF1} \sum_{m=1}^{lF2} (x_{k,l,m} - \bar{x})^2$$

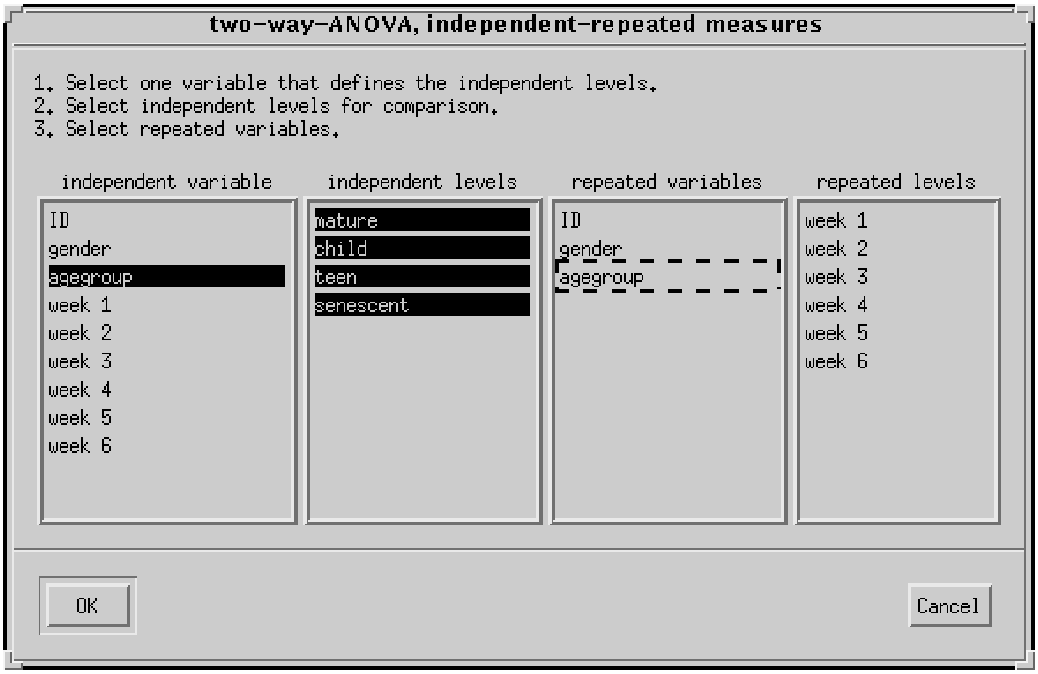
As always, the mean squares are calculated as the ratio of the sum of squares and the respective degrees of freedom.

$$MSS = \frac{SSS}{df\_S} \quad MSSF1 = \frac{SSF1}{df\_F1} \quad MSSF1E = \frac{SSF1E}{df\_F1E} \quad MSSF2 = \frac{SSF2}{df\_F2}$$

$$MSSF2E = \frac{SSF2E}{df\_F2E} \quad MSSF1F2 = \frac{SSF1F2}{df\_F1F2} \quad MSSF1F2E = \frac{SSF1F2E}{df\_F1F2E}$$

8.7.2 Independent-Repeated Design

A question addressed by this design would be, if the age of a test-taker determines if IQ-scores obtained in repeated IQ-tests differ from each other. The age is the independent factor, since each subjects belongs only to one specific agegroup. In addition, the results of the repeated IQ-tests is the second, repeated (or dependent) factor, since each subject performed repeated tests. Thus, the results of later IQ-tests is related to the results of the former IQ-tests.



two-way-ANOVA, independent-repeated measures

1. Select one variable that defines the independent levels.
2. Select independent levels for comparison.
3. Select repeated variables.

Figure 8.10: The ANOVA-two-way, Independent-Repeated Measures dialog

To actually calculate this test, we need to open the dialog box that can be reached by the Statistics ANOVA-two-way Independent-Repeated Mesures menu item (Fig. 8.10). In our example, we would select the agegroup as the independent factor. This automatically selects all levels of this factor (mature, child, teen, and senescent). Now we need to select the repeated variables, e.g. week 1, week 2, week 3, week 4, week 5, and week 6. Then we can start the calculation by clicking on the OK button. This opens the results window shown in table 8.8.

This table provides P values for the between factor (agegroup), the within

ANOVA (two-way) for independent and repeated measures

Source	df	Sum of Square	Mean Square	F	P
Between	25	22880.00464			
agegroup	3	872.30347	290.76782	0.291	0.831655
error	22	22007.70117	1000.35004		
Within	130	4370.83516			
repeated	5	1791.56934	358.31387	16.243	0.000000
interaction	15	152.67256	10.17817	0.461	0.954770
error	110	2426.59326	22.05994		

Table 8.8: 2-way-ANOVA table for independent and repeated measures

factor (time point of IQ-test) and the interaction of the within and between factors. The interaction is significant, if it depends on the agegroup, if the results of the IQ-test depends on the time when the test was performed. In our example, the factor agegroup is not significant (P>0.05). Thus, there is no difference in the IQ in different agegroups. This is the anticipated result, since the IQ-tests are usually standardized for age. However, the within factor is significant (P<0.05), indicating, that the results of the IQ-tests changes when the tests are repeated on successive weeks. Specifically, the result of the IQ-test becomes better, the more often the test is repeated. This may reflect a "learning effect". Finally, the interaction is not significant (P>0.05) indicating, that the age does not modify the behaviour of the test results over time. Specifically, in all agegroups, the test results become better when the tests are repeated.

Calculation of the values in the 2-way-ANOVA table for independent and repeated measures is rather complicate. Especially helpful in implementing this function was the book by Brandt [1] and, again, the Hyperstat internet page by David M. Lane [4]. The details are provided in the following schematic:

Source	df	Sum of Square	Mean Square	F	P
Between	n-1	SSB + SSBE			
agegroup	i-1	SSB	MSB	MSB/MSBE	$F_{i-1,\ n-i}$
error	n-i	SSBE	MSBE		
Within	n*(j-1)	SSW+SSBW+SSBWE			
repeated	(j-1)	SSW	MSW	MSW/MSBWE	$F_{j-1,\ (n-i)(j-1)}$
interaction	(i-1)*(j-1)	SSBW	MSBW	MSBW/MSBWE	$F_{(i-1)(j-1),\ (n-i)(j-1)}$
error	(n-i)*(j-1)	SSBWE	MSBWE		

n: number of subjects
i: number of levels of the independent factor
j: number of levels of the repeated factor
$\bar{x}$: mean of all values
ni: number of values in an independent subgroup
$\bar{xi}$: mean of all values in an independent subgroup
nsi: number of subjects in an independent subgroup
$\bar{xsi}$: mean of all repeated values of only one subject
$\bar{xir}$: mean of all values of a repeated variable for only one independent subgroup
nj: number of values in a repeated variable
$\bar{xj}$: mean of all values in a repeated variable

$$SSB\ (between) = \sum_{k=1}^{i} ni_k(\bar{xi}_k - \bar{x})^2$$

$$SSBE\ (between\ error) = \sum_{k=1}^{i}\sum_{l=1}^{nsi_k} j(\bar{xsi}_{l,k} - \bar{xi}_k)^2$$

$$SSW\ (within) = \sum_{m=1}^{j} nj_m(\bar{xj}_m - \bar{x})^2$$

$$SSBW\ (interaction) = \sum_{k=1}^{i}\sum_{m=1}^{j} nsi_k(\bar{xir}_{m,k} + \bar{x} - \bar{xi}_k - \bar{xj}_m)^2$$

$$SSBWE\ (interaction\ error) = \sum_{k=1}^{i}\sum_{l=1}^{nsi_k}\sum_{m=1}^{j}(x_{m,l,k} - \bar{x})^2 - SSB - SSBE - SSW - SSBW$$

$$MSB = \frac{SSB}{i-1}$$

$$MSBE = \frac{SSBE}{n-i}$$

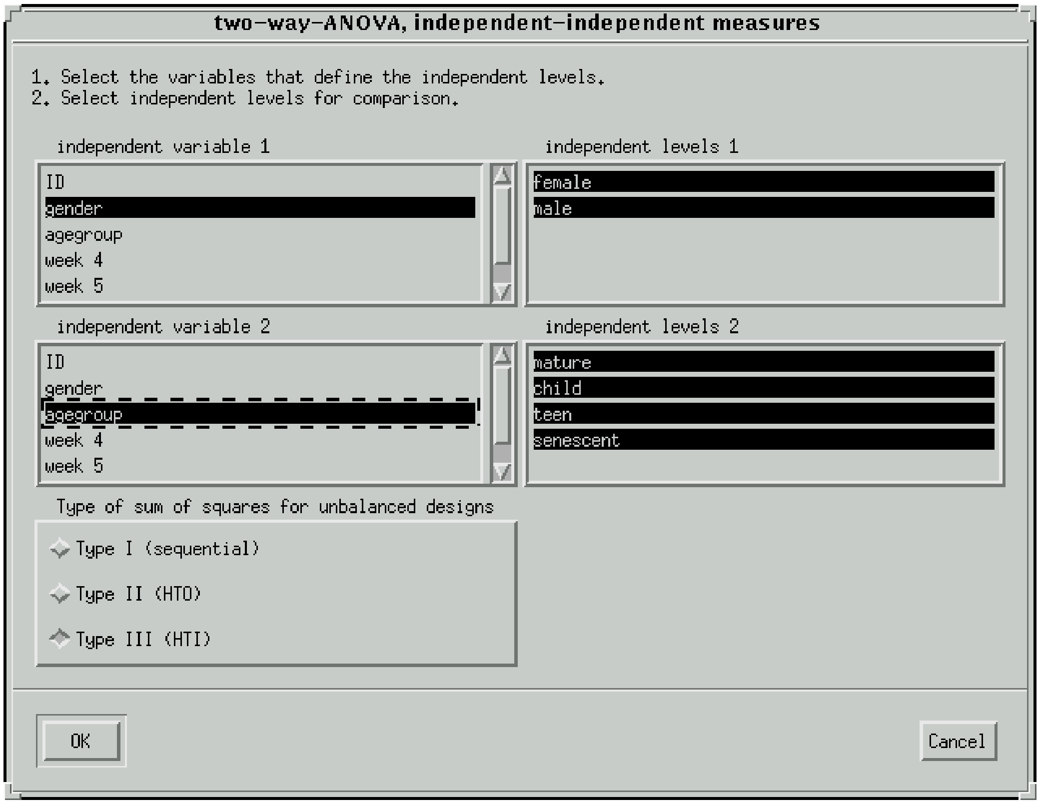
$$MSW = \frac{SSW}{j-1}$$

$$MSBW = \frac{SSBW}{(i-1)*(j-1)}$$

$$MSBWE = \frac{SSBWE}{(n-i)*(j-1)}$$

8.7.3 Independent-Independent Design

A two-way ANOVA with two independent factors would be appropriate, if the question is how the IQ-scores depend on the gender, the age, and the interaction of both parameters. Both factors (gender and age) are independent, since each subject belongs only two one gender and one agegroup. In addition, this design allows to investigate the interaction of both factors, i.e. the question, as to whether it depends on the gender, if there are effects of age on the IQ-scores. Alternatively, the question may be, if it depends on the age, if there is a dependency of the IQ-scores on gender.



two-way-ANOVA, independent-independent measures

1. Select the variables that define the independent levels.
2. Select independent levels for comparison.

independent variable 1: ID, **gender**, agegroup, week 4, week 5

independent levels 1: **female**, **male**

independent variable 2: ID, gender, **agegroup**, week 4, week 5

independent levels 2: **mature**, **child**, **teen**, **senescent**

Type of sum of squares for unbalanced designs

◇ Type I (sequential)

◇ Type II (HTO)

◆ Type III (HTI)

Figure 8.11: The ANOVA-two-way, Independent-Independent Measures dialog

Fig. 8.11 shows the dialog box for the two-way ANOVA with two independent measures. Before opening this dialog box (Statistics, ANOVA-two-way, Independent-Independent Measures), dependent variables must be selected, on which the ANOVA will be calculated. Then, the two independent factors and the levels of the two factors must be selected. Finally, a method must be selected for the calculation of the sums of squares in the case of an unbalanced design. An unbalanced design is a design, in which the number of subjects in each subgroup (e.g. gender-age combination) is not the same. The dataset iq.stat, provided in the example directory reveals an unbalanced design, since there are 4 mature females, but only 2 senescent male subjects. Finally, we can start the calculation by clicking on the OK BUTTON. This opens the results window shown in Table 8.9.

ANOVA (two-way) for independent measures
(Type III (HTI) for unbalanced designes)

week 1	df	sum of squares	mean squares	F	P
Betw. Subj	25	6064.46143			
gender	1	2245.68823	2245.68823	14.921516	0.001140
agegroup	3	336.91888	112.30629	0.746221	0.538530
Interaction	3	991.09363	330.36454	2.195113	0.123870
Error	18	2709.00000	150.50000		
Total	25	6282.70074			

Table 8.9: 2-way-ANOVA table for independent measures

The ANOVA-table provides three P-values, one for each independent variable and one for the interaction of both variables. In this example, there is a clear effect of the gender (males have higher IQ-scores), while the agegroup does not matter (IQ-scores are adjusted for age). The interaction is also not significant ($P>0.05$). If it were significant, it would mean that it depends on the gender, if there is a change in the IQ-scores with age.

Calculation of the values in the 2-way-ANOVA table for independent measures is straight forward, if there is a balanced design (same number of observations in each subgroup). In the case of an unbalanced design, calculation of the sums of squares becomes difficult. In this software, the algorithm described by Donal B. Macnaughton [5, 6] was used. This algorithm provides three different types of sums of squares:

- Type I: sequential sums of squares. The sums of squares depend on the order in which the two factors are defined. This is typically not desired.
- Type II: Higher-level Terms are Omitted (HTO). With this method, the sums of squares do not add up to the same value as SST.
- Type III: Higher-level Terms are Included (HTI). With this method, the sums of squares do not add up to the same value as SST. This is typically the best choice.

Type III, marginal sums of squares are corrected for as many other factors in the model as possible. They also provide estimates which are not a function of the frequency of observations in any group, i.e. for unbalanced data structures, where we have unequal number of observations in each group, the group(s) with more observations do not per se have more importance than group(s) with fewer observations. For purely nested designs, some polynomial regressions, and some models involving balanced data fitted in the right order, we can sometimes need Type I, sequential sums of squares.

Source	df	Sum of Square	Mean Square	F	P
ind. var. 1	i-1	SSV1	SSV1/(i-1)	(SSV1/(i-1))/MSE	$F_{i-1,\ dfe}$
ind. var. 2	j-1	SSV2	SSV2/(j-1)	(SSV2/(j-1))/MSE	$F_{j-1,\ dfe}$
interaction	(i-1)*(j-1)	SSI	SSI/((i-1)*(j-1))	(SSI/((i-1)*(j-1)))/MSE	$F_{(i-1)(j-1),\ dfe}$
error	dfe	SSE	MSE		
total	n-1	SST			

i	number of levels for factor 1
j	number of levels for factor 2
n	total number of observations in ANOVA
dfe	n-1-(i-1)-(j-1)-(i-1)*(j-1)
SSV1	sum of squares for factor 1
SSV2	sum of squares for factor 2
SSI	sum of squares for interaction
SSE	sum of squares for error term
SST	total sum of squares
MSE	SSE/dfe

8.8 Non-Parametric Tests

These tests differ from the t-test or the ANOVA in that they do not require that the data are sampled from a normal distribution. As with the t-test and the ANOVA there are tests available for comparing two independent groups or two repeated observations versus more than two independent groups or more than two repeated observations. Importantly, appropriate tests for paired versus unpaired samples must be selected.

8.8.1 Wilcoxon Signed-Rank Test for paired observations

This test was developped by Frank Wilcoxon and Roberta A. Wilcox and is described in [13]. It can be used if two repeated measurements are obtained in each individual subject, i.e., each observation of the first sample is paired or associated with a particular observation of the second smaple. The test will then determine the probability that the samples have been taken from populatons having the same means. Importantly, the test does not require normal-distribution of the data or the populations from which the data are taken.

For example, in our example of IQ values we may ask if the IQ values in females and males differ when the IQ test was taken in week 1 or in week 6. We would select gender as a sort variable. In the Wilcoxon Test dialog box we will add variable "week 1" to List 1 and variable "week 6" to List 2. The output table of the Wilcoxon Signed-Rank Test for this analysis is shown in Table 8.10:

```
Wilcoxon Signed-Rank Test for Paired Observations

    gender =     female
--------------------------------------------------------------------------
variable 1 variable 2    n  Median1  Median2  SR+  SR-     W      z      P
--------------------------------------------------------------------------
    week 1     week 6   14   85.500  103.000    0   14  -105  3.296  0.001
--------------------------------------------------------------------------

    gender =       male
--------------------------------------------------------------------------
variable 1 variable 2    n  Median1  Median2  SR+  SR-     W      z      P
--------------------------------------------------------------------------
    week 1     week 6   12  106.000  103.500    7    4    19  0.845  0.398
--------------------------------------------------------------------------
```

Table 8.10: Output table for the Wilcoxon Signed-Rank Test.

Apparently females did better at week 6 (median=103.0) than at week 1 (median=85.5), whereas males did not obtain different IQ values in week 1 (median=106.0) and week 6 (median=103.5).

The test is based on the differences between the values of the individual pairs of data. The number of positive and negative differences are provided in the output table of WinStat as "`SR+`" and "`SR-`". These two values do not necessarily add up to the total number of paired observations because differences of zero are excluded from the analysis. The test statistic "`W`" is the sum of all differences. For large number of data pairs, the parameter "`W`" is normally distributed. Therefore, "`W`" can be converted to a "`z`" value using the equation:

$$z = \frac{W}{\sigma_W}$$

The standard deviation σ_W is calculated according to:

$$\sigma_W = \sqrt{\frac{n(n+1)(2n+1)}{6}}$$

The P-value can then be obtained from the normal distribution based on the "`z`" value. the `P`-values in the output table of WinStat is based on a two-sided hypothesis. If a one-sided hypothesis is tested, the P-values should be divided by 2.

8.8.2 Mann-Whitney U-Test for independent groups

This test has also been described by Wilcoxon and Wilcox [13]. It allows to compared data sampled from two independent groups. Again, no normal-distribution of the parameters measured or the population from which the data are sampled is required.

An example (based on the example data set iq.stat) would be if we are interested in the question if there are gender differences in the intelligent quotients (IQ) in children, teens, mature, and senescent test persons at the first time, the IQ-test is presented to the candidates. We would select the variable *agegroup* as a sort variable and the variable *week1* as the dependent variable. Then we would select the *Mann-Whitney U-test* from the *Non-Parametric* submenu of the *Statistics* menu. Now we select the variable *gender* as the variable that defines the two groups. Of course, this variable has only two levels (male and felmale) that are already selected as the levels that should be analysed. The results window that appears after hitting OK button is shown in Table 8.11 and reveals that a significant gender difference exists in mature and senescent candidates.

The Mann-Whitney U-test is based on a rank-sum test. Basically, the data from both groups are combined and sorted in ascending order. The smallest value will be assigned a rank of 1, the second smallest a rank of 2 etc. Equal observations are assigned the mean of the ranks occupied by those observations. For each sample, the sum of the ranks `R` is calculated. Then a `U-value` is calculated for both samples using the number of observations in the respective sample (`n`) and the corresponding sum of ranks (`R`):

$$U = R - \frac{n(n+1)}{2}$$

In the output table of WinStat the `R-` and `U-values` are only provided for the group with the smaller `U-value`. For large samples the `U-values` are normally distributed and can be transformed to a standard normal distribution (with mean 0 and variance 1) by:

$$z = \frac{U - \mu_U}{\sigma_U}$$

```
Mann-Whitney U-test for Independent Observations
Group 1: gender = female
Group 2: gender = male

  agegroup =      child
--------------------------------------------------------------------------
             n1   n2   median1   median2         R         U      z      P
--------------------------------------------------------------------------
    week 1    3    3    93.000   110.000     8.000     2.000  1.091  0.275
--------------------------------------------------------------------------

  agegroup =     mature
--------------------------------------------------------------------------
             n1   n2   median1   median2         R         U      z      P
--------------------------------------------------------------------------
    week 1    4    4    89.500   110.000    10.000     0.000  2.309  0.021
--------------------------------------------------------------------------

  agegroup =  senescent
--------------------------------------------------------------------------
             n1   n2   median1   median2         R         U      z      P
--------------------------------------------------------------------------
    week 1    4    2    85.000   122.500    10.000     0.000  1.852  0.064
--------------------------------------------------------------------------

  agegroup =       teen
--------------------------------------------------------------------------
             n1   n2   median1   median2         R         U      z      P
--------------------------------------------------------------------------
    week 1    3    3    86.000    95.000     9.000     3.000  0.655  0.513
--------------------------------------------------------------------------
```

Table 8.11: Output table for the Mann-Whitney U-Test

μ_U and σ_U are the mean and standard deviation of `U` if the null hypothesis is true and are given by (n_1 and n_2 are the number of observations in the two groups):

$$\mu_U = \frac{n_1\ n_2}{2}$$

$$\sigma_U = \sqrt{\frac{n_1\ n_2\ (n_1 + n_2 + 1)}{12}}$$

Finally, the P-value that corresponds to the z-value is looked up in the normal distribution function. Again, the P-value is for a two-sided hypothesis. If a one-sided hypothesis is tested, the P-value should be divided by 2.

Chapter 9

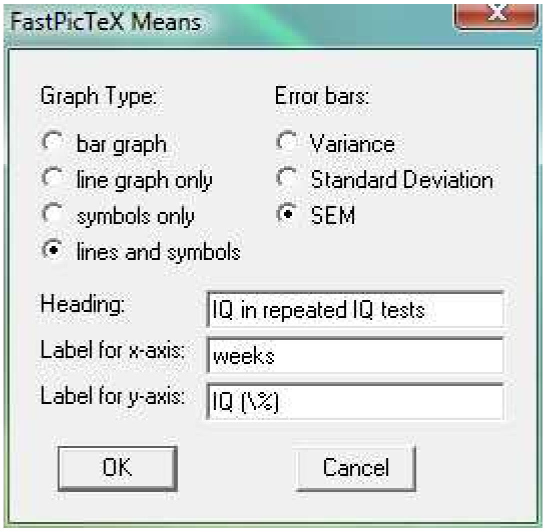
FastPicTeX Commands

FastPicTeX is a preprocessor for PiCTeX [12]. PiCTeX is a LaTeX package for typesetting graphical material. LaTeX is a typesetting software that is freely available for a variety of operating systems, including Unix, Windows, DOS, MacOS, and others. One example of a free LaTeX distribution is MikTeX. Thus, to make use of the FastPicTeX commands in WinStat, one needs to have LaTeX with the PiCTeX package installed on the computer. The FastPicTeX commands from WinStat generate FastPicTeX files, that can be processed by the FastPicTeX software that cames with HemoLab. The FastPicTeX software is also available from DANTE and from ftp.sunsite.unc.edu. The FastPicTeX software then generates a PiCTeX file that can be included in LaTeX documents. LaTeX can generate output of the graphs in a variety of file formats, including postscript and PDF.

9.1 Means

The FastPicTeX Means command is used to generate diagrams of the mean values of the data set. The command opens the FastPicTeX Means dialog box shown in Fig. 9.1.

In this dialog box you can select from four graph types and three types of error bars. You can also type in a heading and labels for the x-axis and y-axis of the diagram. The heading and axis labels must be in LaTeX syntax (e.g., “\%” for the percent sign). Once you hit the OK button, a new dialog box opens for selection of the output file (*.fpt) that contains the FastPicTeX code.



FastPicTeX Means

Graph Type:
○ bar graph
○ line graph only
○ symbols only
● lines and symbols

Error bars:
○ Variance
○ Standard Deviation
● SEM

Heading: IQ in repeated IQ tests
Label for x-axis: weeks
Label for y-axis: IQ (\%)

Figure 9.1: The FastPicTeX Means dialog box.

9.1.1 More than one dependent variables

If more than one dependent variable is selected, the dependent variables are plotted on the x-axis. If sort variables are selected in addition to multiple dependent variables, the different sort groups will be represented as series in the resulting diagram. For example, if we select weeks 1-6 as dependent variables and gender as sort variable in the IQ data set, the FastPicTeX Means command will generate the following FastPicTeX file that encodes the diagram shown in Fig. 9.2:

```
% ......   start of FastPicTeX file generated by WinStat   ......
size 8 6
heading IQ in repeated IQ tests
xlabel weeks
ylabel IQ (\%)
xticlabels "w1" "w2" "w3" "w4" "w5" "w6"
type line
type xy
legend
legend female
x
x
y 88.000000 89.285713 94.000000 97.428574 101.071426 105.500000
dy 3.205421 3.209581 2.739616 3.062920 3.129906 3.093328
```

```
y 88.000000 89.285713 94.000000 97.428574 101.071426 105.500000
dy 3.205421 3.209581 2.739616 3.062920 3.129906 3.093328
type line
type xy
legend
legend male
x
x
y 106.333336 103.416664 102.833336 103.166664 103.583336 105.583336
dy 3.914490 2.978352 3.522296 4.466769 3.621188 3.589670
y 106.333336 103.416664 102.833336 103.166664 103.583336 105.583336
dy 3.914490 2.978352 3.522296 4.466769 3.621188 3.589670
```

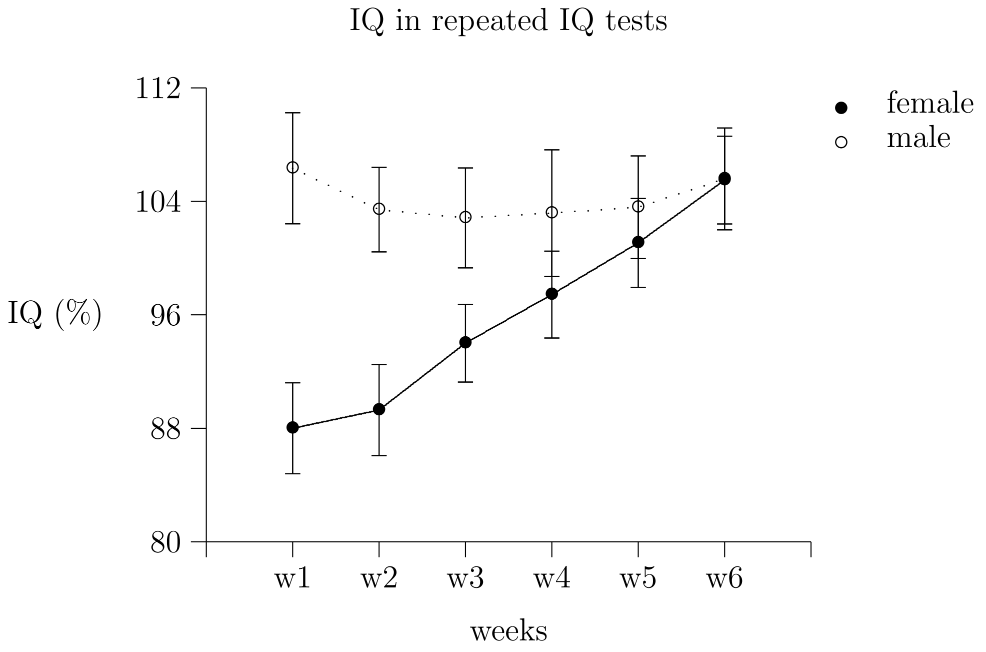


Figure 9.2: A FastPicTeX diagram with the dependent variables at the x-axis. The variable names were changed from “week 1”, “week 2”, etc. to “w1”, “w2”, etc. to avoid overlapping x-axis tic labels.

9.1.2 Only one dependent variable

Let’s discuss the case when only one dependent variable is selected in addition to one or many sort variables. In this case, the first sort variable defines the x-axis and the next sort variables define different series. For example, if we select the `agegroup` variable as first sort variable, the `gender` variable as second sort variable, and the `week 1` variable as dependent variable, the command FASTPICTEX MEANS generates the following FastPicTeX file and the diagram shown in Fig. 9.3:

```
% ......   start of FastPicTeX file generated by WinStat   ......
size 8 6
heading IQ at different ages
xlabel agegroups
ylabel IQ (\%)
xticlabels child mature senescent teen
type bar
legend female
x 1 2 3 4
y 87.333336 88.250000 84.250000 93.333336
dy 5.666667 5.072392 2.688711 13.775986
type bar
legend male
x 1 2 3 4
y 101.000000 110.500000 122.500000 95.333336
dy 10.535654 3.685557 7.500000 2.603417
```

9.1.3 How to generate the graphs

To generate the actual figures (or graphs) from the FastPicTeX files generated by WinStat, three steps are necessary:

1. Run the FastPicTeX file through fastpictex to generate the PicTeX file. This is done by the command:
   `fastpictex graph.fpt graph.ltx`

2. Run the resulting `graph.ltx` file through LaTeX. Therefore, you need a small LaTeX file that includes the `graph.ltx` file. This LaTeX file (e.g., image.ltx) can be as simple as:

   ```
   \documentclass[12pt]{report}
   \usepackage{pictex}
   \begin{document}
   \input graph.ltx
   \end{document}
   ```

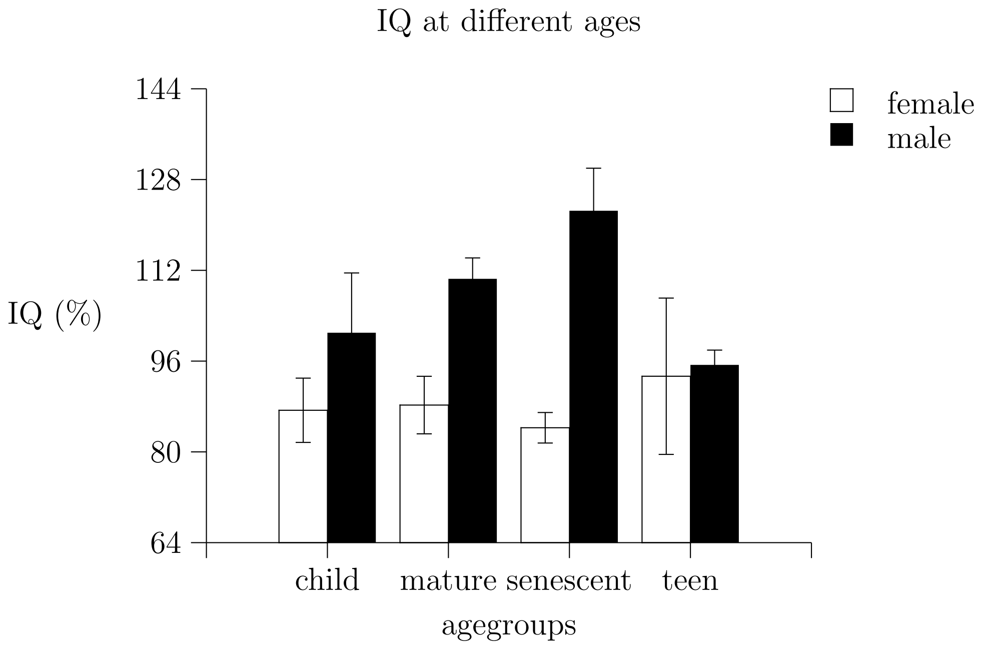


Figure 9.3: A FastPicTeX diagram with the first sort variable (`agegroup`) at the x-axis. The second sort variable (`gender`) defines the two series of this graph. The dependent variable is `week 1`.

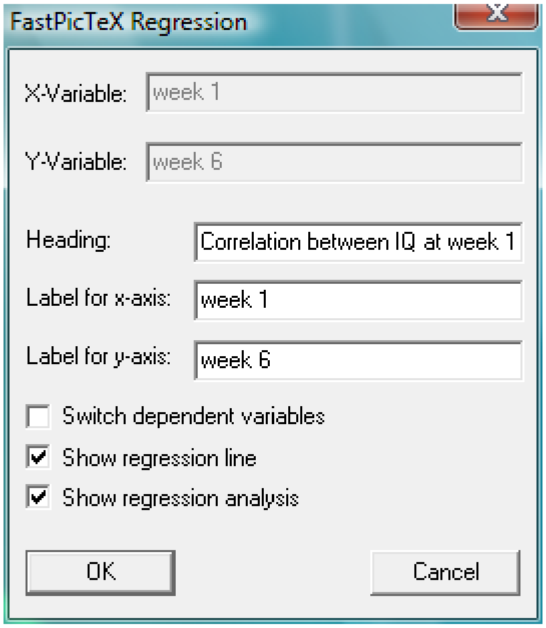
3. The step above generates a new file with the extension `.dvi` (e.g., `image.dvi`). This file can be converted to a PDF file by the command:
   `dvipdfm image.dvi`
   The `dvipdfm` program typically comes with the LaTeX distribution (at least it came with MikTeX that I used when writing this manual).

I know, it sounds somewhat complicate. However, once you have figured it out, it is really easy and fast.

9.2 Regression

The FastPicTeX Regression command is used to generate diagrams of the correlation between two variables. Thus, exactly two dependent variables must be selected. Sort variables can also be selected. The FastPicTeX Regression command brings up the dialog box shown in Fig. 9.4.

The names of the X- and Y-variables are shown on the top of the dialog box. The next three edit fields allow to enter a heading and labels for both



X-Variable: week 1

Y-Variable: week 6

Heading: Correlation between IQ at week 1

Label for x-axis: week 1

Label for y-axis: week 6

☐ Switch dependent variables

☑ Show regression line

☑ Show regression analysis

Figure 9.4: The FastPicTeX Regression dialog box.

axes using the LaTeX syntax. The X- and Y-variables can be switched by selecting the corresonding check box. One can also decide if a regression line should be drawn and if the linear regression equation should be added to the figure legend by marking the appropriate check boxes.

Assuming we want to visualize the correlation between the IQ values of males and females obtained in week 1 and week 6. We would then select the variables week 1 and week 6 as dependent variables and gender as sort variable. The FastPicTeX Regression dialog box is shown in Fig. 9.4. An appropriate heading and axes labels should be entered. Since we want to see the regression lines and the linear regression equations, we mark the respective check boxes and hit the OK button. We will be asked for an output filename for the resulting FastPicTeX file. This command generates the FastPicTeX file shown below. The resulting regression diagram is shown in Fig. 9.5.

```
% ......   start of FastPicTeX file generated by WinStat   ......
size 8 6
heading Correlation between IQ at week 1 and week 6
xlabel week 1
ylabel week 6
type xy
```

```
x 95 84 120 74 93 93 85 76 98 77 90 86 76 85
y 110 100 135 92 112 115 104 98 115 94 109 102 96 95
tline 2
legend female
type xy
x 110 115 110 130 110 100 91 120 113 102 80 95
y 108 114 113 127 110 99 93 116 114 97 85 91
tline 2
legend male
```

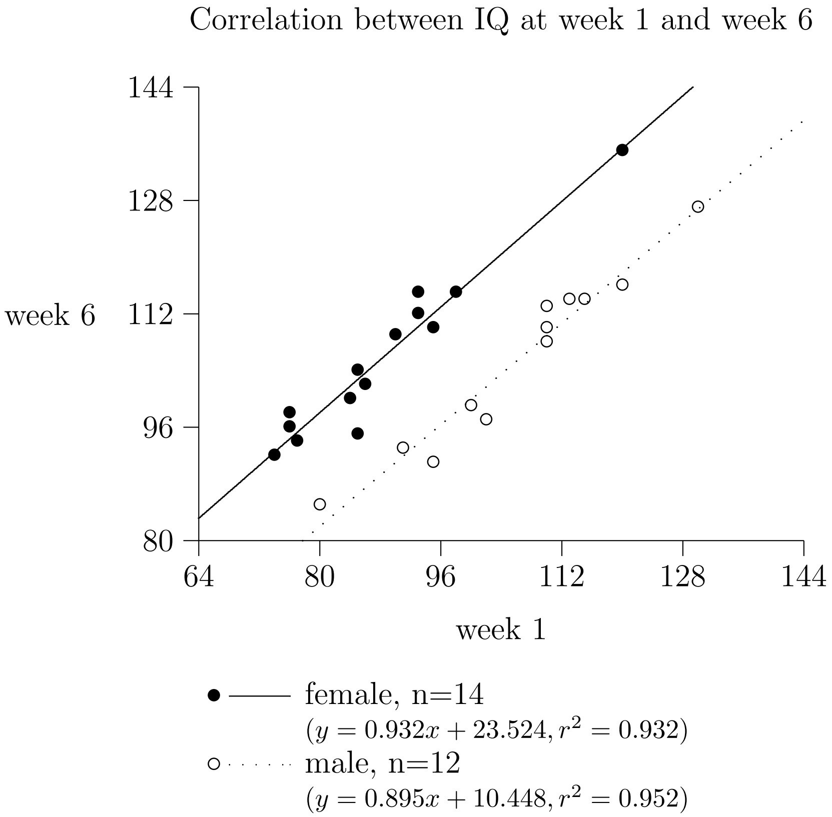


Figure 9.5: A FastPicTeX regression diagram with gender as the sort variable. The LaTeX file generated from the FastPicTeX file was manually edited to move the legend from the right side of the chart to the bottom of the chart.

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